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ELECTROLYTIC CLEANING OF METALS

By Herbert R. Hanley
Professor of Metallurgy
Missouri School of Mines, Rolla

CLEANING of metal surfaces in general implies the removal of the oxide coating without too much damage to the underlying metal. This can be done by various methods, namely, sand blasting, grinding, hydrochloric or sulphuric acid attack, cathodic or anodic electrolysis in a suitable electrolyte.

Acid attack (pickling) or electrolysis in acid solutions leaves the metal surface etched or polished. The difference between electrolytic *etching* (anodic) and electrolytic *polishing* lies in the control of anodic current density and thickness of anode film. A study of the current-voltage curve shows that there is a critical voltage corresponding to some definite current density at which polishing occurs and below which the surface is dissolved or etched.

Removal of scale by acid pickling is standard practice in wire, tube and sheet mills, as a conditioning step in the production of a smooth, bare surface, or to prepare for hot dip galvanizing or tinning. Hydrochloric acid removes the scale by chemical solution; sulphuric acid by combined chemical and mechanical or scrubbing action of the hydrogen gas which is simultaneously evolved. In the latter case the scale broken away (largely magnetic iron oxide, Fe_3O_4) is not soluble in the acid.

There are three kinds of electrolytic cleaning or descaling depending on polarity of the work, namely, cathodic, anodic, and alternate current. Articles subjected to cathodic cleaning

when tested for cracking and endurance limit show lower values than though the work were done by anodic cleaning; hardness is also increased. Fracture sometimes shows a well-defined bright band at the surfaces, indicative of the depth to which hydrogen has penetrated the metal. Rate of penetration increases with increasing current density. This increased hardness and other changes in properties are termed "hydrogen embrittlement". Ordinary pickling in sulphuric acid solution also develops this hardness, but more slowly than it is produced by cathodic action.

Hydrogen Embrittlement

Pickling in hydrochloric acid does not cause hydrogen embrittlement. The reasons are not clear. One explanation (or rationalization) is that frequently there is a trace of arsenic in this acid which acts as an inhibitor by providing a protecting film over the surface of the metal impervious to hydrogen.

In anodic cleaning there is no hydrogen environment and consequently no embrittlement. For this and other reasons this method of descaling is most frequently employed for various difficultly corrodible metals and alloys of high chromium-nickel content.

Further remarks on hydrogen penetration will be given later in a discussion of inhibitors and blisters.

Electrolytic Processes

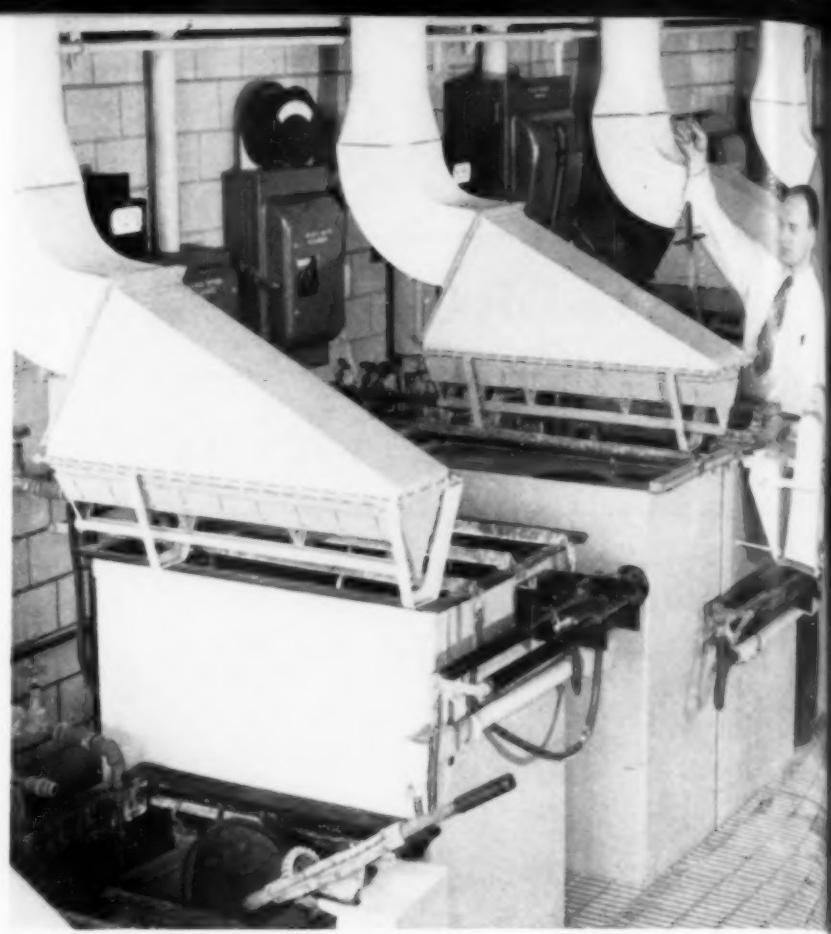
As remarked above, there are three possibilities, namely, anodic, cathodic, and alternate polarity. Numerous variations of electrolyte have been proposed, patented, and put into use. Some are primarily adapted to the high alloy steels.

1. The Bullard-Dunn electrochemical process for metal descaling has been used for over ten years. It was interestingly described by E. T. YODD, chief metallurgist of The Bullard Co., in *METAL PROGRESS* as early as May 1931. He described a sulphate-chloride bath at 170° F., and the lead anodes maintained a trace of lead in solution. At present one recommended adaptation of the process consists of cathodic descaling in a hot sulphate bath containing a small amount of a metal salt such as tin sulphate. A protective film of tin or other metal is progressively formed over the cleaned metal points or areas. All pitting, etching, smudge formation and permanent embrittlement so common in ordinary acid or electropickling are thus avoided.

Cathodic current density is much in excess of that normally used for electroplating. Hydrogen is liberated in large amounts at the surface of the work, and "blasts off" the scale; concurrently a metal film rather than hydrogen is electrodeposited on the work. This metal film raises the throwing power of the solution and does not build up in thickness upon continued electrolysis.

A typical cell which deposits a film of lead on the descaled cathode employs the following electrolyte: H_2SO_4 , 47.5 grams per liter; HCl , 10.3 g.; $NaCl$, 22.5. Temperature 150 to 180° F., current density 75 amperes per sq.ft. The process removes all scale in 3 to 5 min. If traces of the lead or other metallic film must be removed from the work it can be done by operating the work as an anode for a short time in an alkaline electrolyte ($NaOH$, 90 grams per liter; Na_3PO_4 , 30 grams per liter) at 200° F.

When the iron concentration reaches 22.5 grams per liter, part of the electrolyte is discarded. Ferric iron is objectionable in the bath, but ferrous iron can be tolerated even at concentration approaching saturation. The iron is



Tanks and Barrels for Studying Electrolytic Processes in New Research and Service Laboratory, R. & H. Chemicals Dept. of the Du Pont Co. at Niagara Falls, N. Y.

maintained in the ferrous condition by the use of silicon-iron alloy anodes (duriron). The principle upon which these anodes function is as follows: Anodic environment produces a thin, integral, inert and porous diaphragm composed primarily of silica which very soon completely covers the active anode surface, but does not increase in thickness at an appreciable rate. This provides a long, useful life for the anode. The covering layer prevents the oxidation of ferrous iron to ferric, and hence is equivalent to a separate porous diaphragm.

The Bullard-Dunn process is a descaler rather than a polisher. In other words, forgings or heat treated articles would ordinarily be descaled and the work then ground and polished in the ordinary way, after which the pieces are ready for electroplating.

Processes for Stainless

Three processes were described by SAM TOUR in *Metals and Alloys* for October 1941, as follows, as being suitable for stainless as well as common steels:

2. The BLANT-LANG process (U. S. Patent 2,115,005) in which the original surface is treated anodically in a bath of H_2SO_4 or HF. The anodic

pickling action involves primarily not a dissolution of the scale, which like most oxides is very difficult to dissolve, but rather a loosening of the scale due to the penetration of the electrolyte to the underlying metal surface and subsequent evolution of gas.

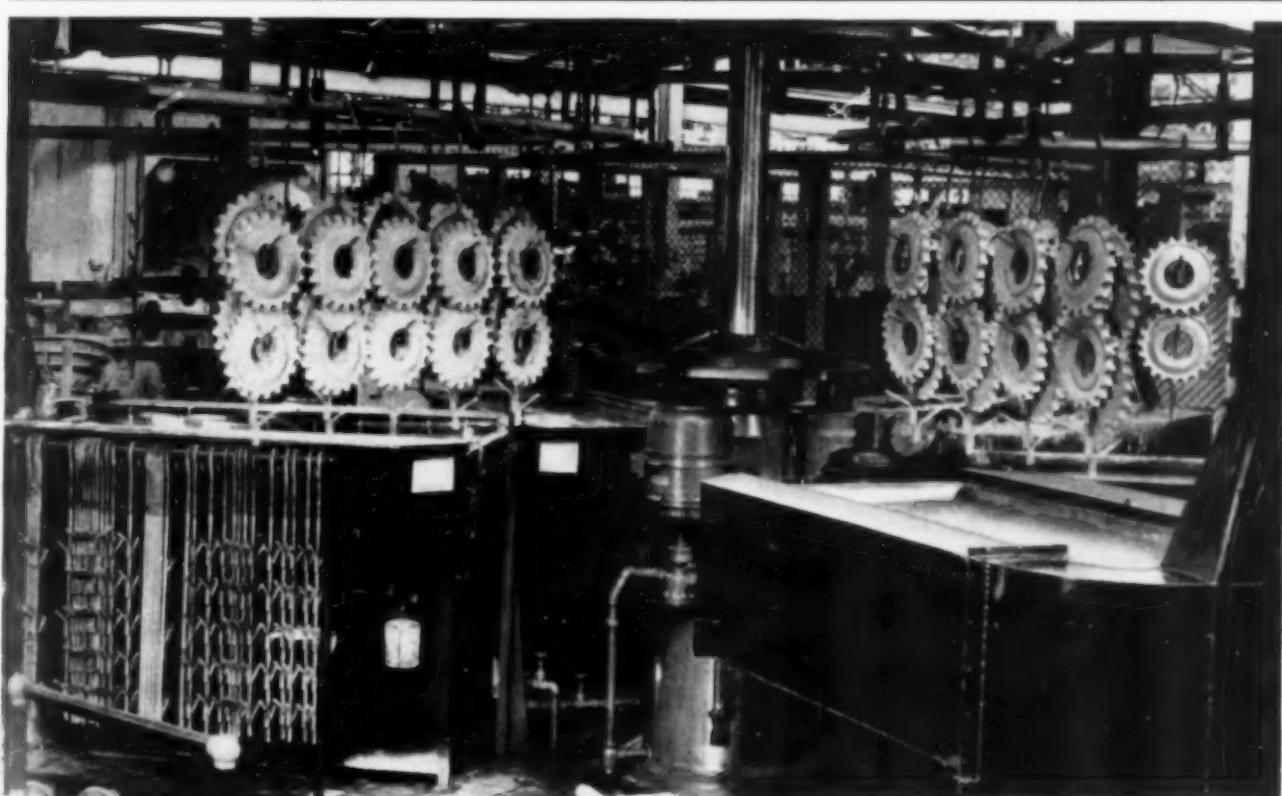
3. The S. F. URBAN process (U. S. Patent 2,172,041) which uses HF, CrO₃ and H₂SO₄ as a still pickle for steels containing more than 12% chromium.

4. Nickel and its alloys, especially those of high chromium content, can be descaled with great speed and cleanliness by anodic pickling in baths of H₃PO₄ and H₂SO₄. (Electrolytic polishing can be accomplished by varying the temperature and current density.) Continuous descaling and electrolytic polishing of strip and wire or individual pieces on a conveyor can be done by passing through a two-compartment tank containing the same electrolyte, but providing suitable physical conditions in each.

5. "Critical Points" in METAL PROGRESS for April 1941 described a recent electrolytic process for removing scale from stainless steel rod. The chromium oxides that are formed at high temperatures are notoriously hard to cut by

acid, so the scaled metal is hung for a few minutes in a large tank of molten caustic (at about 750° F.) and made cathodic by an electric current of about 25 amperes per sq.ft. Sodium plates out on the metal, tending to reduce the oxides without attacking the metal underneath. From this the rods are quenched in water, then transferred to sulphuric acid solution to soften final traces of oxide. The steel is then fairly clean, and in such shape that the subsequent dip in nitric-hydrofluoric acid solution and a final wash cleans the surface perfectly and promptly.

6. Anodic pickling of iron and steel in ferrous sulphate solution containing 0.3% H₂SO₄ is described by MULLER and HORANT in *Transactions of the Electrochemical Society* for 1936, p. 145. A 0.4N FeSO₄ plus 0.3% H₂SO₄ solution at 30° C. is preferred to a 10% H₂SO₄ solution. The former mixture pickles in about 30 min. or half the time required for straight sulphuric acid. This may be due to the depolarizing action of FeSO₄ preventing the iron (anode) from becoming passive. Energy cost is 9¢ per 1000 sq.ft. descaled, on the basis of 1¢ per kw-hr. and current density of 8 amperes per sq.ft.



Descaling Tank Transmission Gears After Heat Treatment, by Bullard-Dunn Process. Tanks are

set radially about hydraulic lift, and work is conveyed from station to station in batches

7. Anodic pickling of high speed steel is described by R. H. ROGERS in *Transactions* of the Electrochemical Society in 1931 (page 357). He recommends that high speed steel parts should be anodically treated at 25 amperes per sq.ft. in an alkaline bath containing 115 grams per liter of NaOH plus 15 grams per liter of citric acid. When the gas evolution is entirely uniform the pickling has been completed. The parts are then washed and dipped for an instant into hydrochloric acid (6 to 12N). If the high speed steel surface is not entirely clean, anodic treatment of the surface at 60 amperes per sq.ft. in a 6N HCl or H₂SO₄ solution for a few seconds, followed by a rinse, and then a second anodic treatment in the alkaline bath, will give the desired results.

Inhibitors

Historical Notes — In 1845 a material which would practically stop the action of acid on iron was discovered by E. MILLION. In 1905 CHARLES F. BURGESS showed that a solution of arsenic in acid would decrease the harmful effects resulting from over-pickling of iron. About the same time additions of As₂O₃ were also used to prevent the corrosion of water jackets of a blast furnace when the cooling water contained a small amount of acid.

OLIVER P. WATTS, in determining the effect of various metal ions for inhibiting power, found that in addition to arsenic, tin and mercury salts would inhibit the action of H₂SO₄ on iron. These metals have a high hydrogen over-voltage, and are charged negatively after being deposited from solution on the iron. The higher potential required at the negatively charged cathode areas increased the difficulty of discharging H⁺ at the plated metal surface, and stopped the action of the acid on the iron.

The first mention of the action of *organic* inhibitors is by MORANGONI and STEPHANELLI in 1872. For a great many years it had been known that the addition of bran shorts, glue, gelatin, and other organic substances prevented evolution of hydrogen in pickling. KENNETH B. LEWIS has the following to say on the subject in his 1941 Mordica Memorial Lecture before the Wire Association:

"I do not know just when or how this boon to humanity (inhibitors) crept into use. I vaguely recall the use of red-dog flour before the World War, but did not hear it discussed. Sulphuric acid in the war years went largely

into the manufacture of explosives, and came back to the wire mill in the form of nitre cake and similar byproducts containing nitrogenous impurities. These had a good deal of merit; they gave us a preview and softened us up for the inhibitor salesman. Inhibitors were important in the history of cleaning, not for the acid they saved so much as for the way they and their associated foam blankets made the cleaning house a place where self-respecting men could live and work, and see what was going on. Following their use there was a notable reduction in dirty wire and a general rise in standards of excellence."

Theory — While the above was long before the advent of electrolytic pickling and polishing, it gives some idea of the background. The very act of dissolution of scale from iron gives an electrolytic cell of comparatively big value. The structure of the scale itself is complex; the outermost layer is approximately Fe₂O₃, the middle layer is Fe₃O₄, and the layer next to the metal is approximately FeO (porous). Since FeO decomposes during cooling at about 574° C. (1065° F.), this phase consists principally of Fe₃O₄ crystals, precipitated from the solid solution above this temperature, in a matrix of very finely divided iron in Fe₃O₄.

When an acid electrolyte is brought into contact with iron covered with a normal scale, several electrolytic cells are possible, among them being

1. Fe / acid / FeO	0.415 volt
2. Fe / acid / Fe ₃ O ₄	1.42
3. Fe / acid / Fe ₂ O ₃	1.18
4. Fe ₃ O ₄ / acid / Fe ₂ O ₃	0.47

This difference in potential combined with the intimate contact between the iron base and the iron oxide of the decomposed ferrous phase layer results in the rapid solution of this ferrous phase. Metallic inhibitors, such as arsenic, protect iron by plating out on the surface of the exposed iron areas and, being negatively charged with respect to the iron, prevent the discharge of hydrogen ion by their high "hydrogen over-voltage".

Organic inhibitors in acid solution are positively charged colloids or organic bases. These positive particles migrate to the vicinity of the negatively charged cathode areas and may be there discharged and adsorbed due to unsatisfied valence bonds. Or they may form a layer of adsorbed positive ions over the negatively charged cathode areas. In either case the discharge of hydrogen ions is inhibited by the

presence of the positively charged film, or the blanketing of the cathode area by the organic film and the consequent increase of interfacial resistance between the electrolyte and the surface of the metal. Their specific effects on the discharge of the hydrogen ion and their mechanisms of operation are not entirely understood. WILLY MACHU, for example, submits experiments in the *Transactions of the Electrochemical Society*, Vol. 72, p. 333, indicating that films are adsorbed over the *entire* surface, but the film is thicker over the bare metal and hence tends to protect those areas. In his view the electrical resistance of the inhibitor film is a direct measure of its effectiveness.

Organic inhibitors cannot be used to prevent furnace pits and defects resulting from breaks in the scale before pickling. The high voltage developed by the scale-iron electrolytic cell appears to be too great to inhibit.

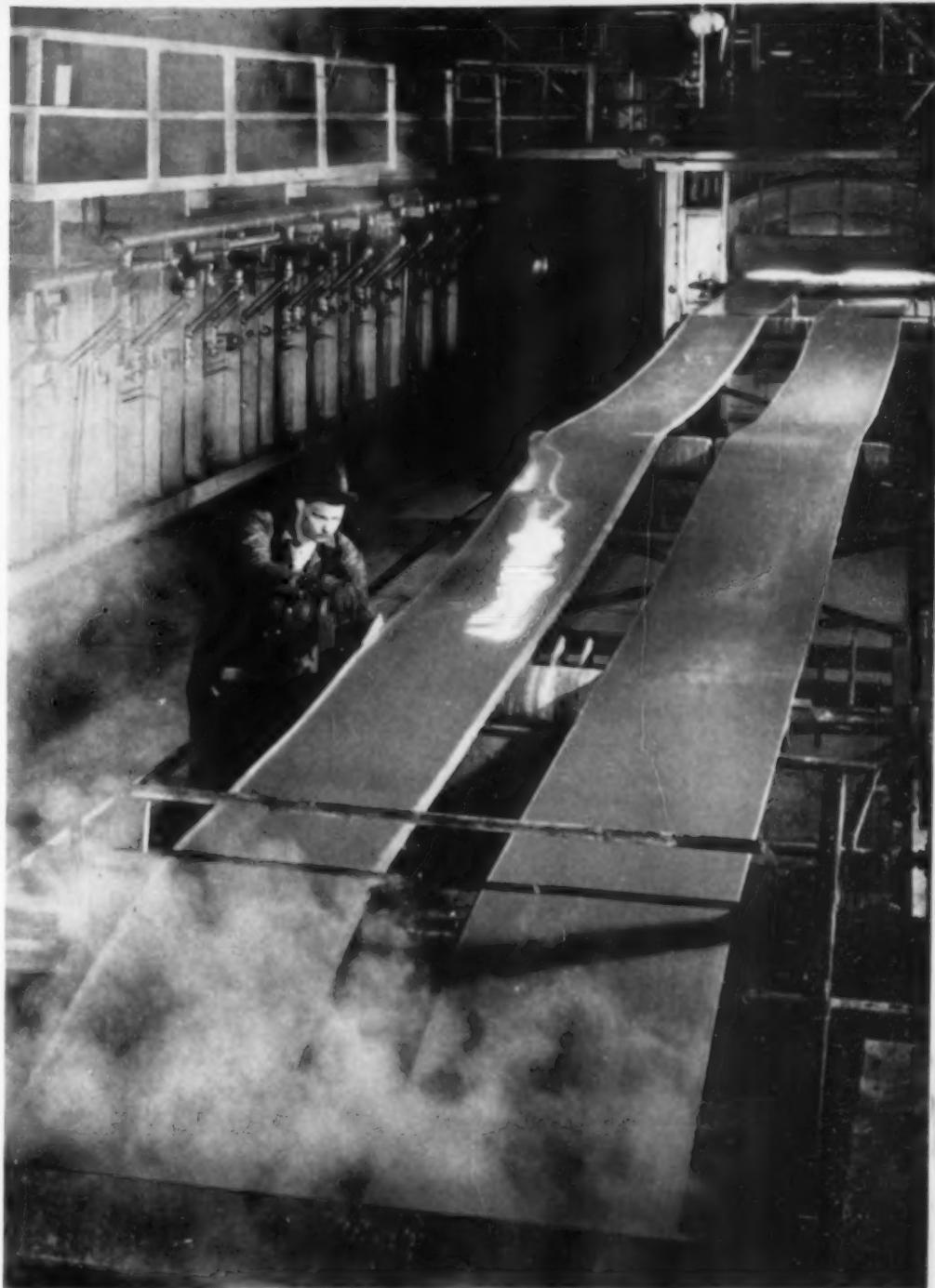
Measurements of the interfacial resistance (apparent over-voltage) have been used to estimate the effect of inhibitors. Thus, gelatin and an extract of coal tar bases was found to increase the interfacial resistance at the negatively charged electrode and decrease the hydrogen evolution in about the same proportion.

Although organic inhibitors affect the reaction at negatively charged areas, the inorganic inhibitors, such as arsenates, phosphates, silicates, and chromates, inhibit the reaction at the *positively* charged areas.

Inhibitors are useful adjuncts to pickling solutions if their cost is not too great, or if their presence does not interfere with the subsequent treatment or fabrication of the steel. For instance, inhibitors can do a lot of damage to the galvanizing or enameling operation unless used with understanding care.

Blisters

A large literature has appeared on defects especially on tinned, galvanized and enameled



Wide Stainless Steel Strip Passing From a Normalizing Furnace Into a Continuous Electrolytic Pickling Unit at Massillon Plant of Republic Steel Corp.

goods, which appear to originate from the expansion of a gas pocketed within the steel sheet. This gas is commonly said to be hydrogen, and it is also commonly supposed to have been absorbed from the pickling solution.

Atomic hydrogen will diffuse through metal, but inhibitors reduce the amount of it. Presence of sulphur-bearing compounds in the pickling bath greatly increases the amount of hydrogen which diffuses into the steel. The form of the iron carbide in the steel also appears to have a definite effect on the rate of diffusion of hydrogen; spheroidized cementite permits the highest rate of diffusion, while lamellar pearlite shows the lowest rate.

OUR BIOGRAPHICAL DICTIONARY



Champion Herbert Mathewson

INVESTIGATOR, TEACHER, METALLURGIST

CHAMPION HERBERT MATHEWSON

IN 1885, during the formative period of Sheffield Scientific School, there was established the professorship of metallurgy in Yale University. The first incumbent, Professor BRUSH, was more interested in mineralogy than metallurgy; later professors were primarily assayers, chemists or mining engineers. That is not so surprising; Yale University, in thus pioneering the way, merely exhibited the general pattern of other institutions in America which approached the problem of engineering education. "Metallurgy" then meant smelting; any scientific control of smelting that existed was exercised by the assayer (or the chemist in the iron or steel plant — men who, in the opinion of the practical foremen, were sure to ruin the business with their new-fangled ideas).

Even as late as the turn of the century, 45 years after Yale established its chair of metallurgy, the subject was still the adjunct of chemistry or mining engineering in most American colleges. (In some rather slow moving ones, this situation still persists.) But by 1910 it was becoming apparent that even though metals, as well as chemicals and minerals, obeyed fundamental natural laws of science, their performance was so inhibited by the "metallic state" that a separate branch of physics and chemistry was warranted — indeed, *demanded* by the industrial requirements of metals during fabrication and use.

Fortunate indeed it is that Sheffield Scientific School of Yale University then possessed a young man who sensed this demand and was capable of meeting it.

CHAMPION HERBERT MATHEWSON, since 1919 chairman of the Department of Metallurgy, came to the Yale faculty in 1907 as instructor in chemistry and metallography. Himself a Sheffield graduate (1902), he was fresh from advanced study under Professor TAMMANN in Göttingen, who was then pioneering in the systematic study of metallography. In New Haven it was not until 1911 that the routine of teaching freshman chemistry was broken and courses on microscopic metallography and the constitution of alloys were firmly established. Meanwhile MATHEWSON had translated RUER's "Elements of Metallography" (pretty strong stuff, even yet).

The first World War brought calamity to the growing Department of Mining and Metallurgy, housed in a new and excellent laboratory, the gift of JOHN HAYS HAMMOND. At the time of the armistice MATHEWSON was the one sole survivor of a notable faculty, gradually acquired. The calamity was, however, merely an opportunity to start off afresh; obviously metallurgy rather than mining was the important study for post-War students at Yale; product metallurgy, physical metallurgy, was the vital aspect rather than descriptive and chemical metallurgy of ore dressing and smelting.

Based on these principles, the new chairman of the Department of Metallurgy has built a curriculum and faculty that have attracted to Yale a steady stream of men for both undergraduate and advanced instruction — a stream that is measured not in numbers but in a quality best judged by ZAY JEFFRIES' recent remark: "Among these students are some of America's and the world's most able metallurgists."

Professor MATHEWSON's evolution since 1907 may be traced in his many publications. First was a period when he was extending his own graduate work, studying phase relationships in alloy systems. (It is necessary to point out that even this early — 1910 to 1915 — he was 'way ahead of most of his compatriots.) Next he turned attention to a study of the copper alloys produced in the important brass centers near New Haven — their physical properties as affected by rolling mill practice and heat treatment, a field that abounded in closely held "secrets". Finally he was urged to inquire more closely into the causes of such things as he observed. In his words, "Efforts to discover why the things that we observe, in the mechanisms of plastic deformation and heat treatment, for example, *do* occur not only are good for the soul but if carried far enough always have practical consequences." The results are a series of studies into the crystallographic changes during plastic flow (cold work). He quickly came to the conclusion that mere translation of crystalline fragments, a hypothesis widely held, was unable to explain the observed facts, and proposed that change in orientation or twinning was a necessary action. In later

years he more amply substantiated this idea, scientifically, with X-ray crystal analysis. Practically, the scientific principles resulted in useful modifications in the rolling of pure zinc sheet — that traditionally brittle metal.

So much for his pre-eminence as an investigator and a teacher. As a friendly human being, many besides his students bear witness. He is a member of several engineering societies, and is ready to give his time and energy when apparently it is necessary. Only one instance is his assumption of the unwanted chairmanship of American Society for Testing Materials' newly formed committee on copper alloys, laying down the duties only when it was firmly established

and active. Likewise he has freely given of his time and advice on advisory boards to the National Bureau of Standards, Frankford Arsenal, and National Research Council. Among his many honors is the James Douglas Gold Medal, the highest award of the American Institute of Mining and Metallurgical Engineers, with the citation "For his scientific contributions to the art of working and annealing non-ferrous metals".

Most prized, perhaps, is memory of many keen students, who a few months ago on the occasion of his 60th birthday, gathered around a generous table and toasted their teacher and friend, CHAMPION HERBERT MATHEWSON. ☈

STRUCTURE OF ALLOYS*

By William Hume-Rothery

FOR THE LAST eight years the British Non-Ferrous Metals Research Association has lent generous support to research work on the structure of alloys under my direction at Oxford. Much of it has required precise measurements at high temperature, and many improvements in equipment and technique have been devised, and described in the scientific literature. Particularly should be mentioned the matter of preparation and preservation of samples. Most published X-ray investigations, for example, rely upon the erroneous assumptions that filings can be prepared and heat treated without contamination or change in composition, and that the very fine particles sieved out have the same composition as that of the original ingot.

The aim of the work, often involving uncommon elements, has been to establish general principles, in the hope that, once these were grasped, the metallurgist would have such increased power that he might be considerably nearer to the stage at which he could formulate alloys with the properties which were desired. Scientifically, there is nothing more improbable in the idea of building up an alloy of desired properties from a knowledge of the characteristics of the different kinds of atoms, than there is in building up synthetic dye-stuffs with desired colors. The difference between the two problems lies largely in the fact that the chemist works with a soundly established science behind him.

So-called equilibrium diagrams represent the earliest attempts to systematize the data about an alloy, or family of alloys. X-ray studies have revealed the atomic arrangements and established the fact that each alloy phase is based on a definite pattern or arrangement of atoms in space. Electron theories have emphasized the importance of the number of electrons per unit cell of the crystal structure. It follows, therefore, that the general principles underlying alloy formation can be appreciated only by expressing the results in terms of the atomic proportions of the different elements in the alloy, and the metallurgist of the future will inevitably acquire the habit of thinking in terms of atomic and electronic ratios, just as the chemist automatically thinks of sulphuric acid as H_2SO_4 .

Work at the University of Oxford was early centered on substitutional solid solutions (where one atom replaces another upon a common lattice) and a large number of solid solutions of copper and of silver were examined. The principle was advanced in 1934 that, if the atomic diameters of the solvent and solute differ by more than about 14%, the "size factor" is unfavorable and the solid solution is very restricted, while when the atomic diameters are within this limit the "size factor" is favorable, and considerable solid solutions may be formed. Furthermore, where the solubility of one metal in another is limited (*Cont. on p. 280*)

*Abstract of Research Report No. 562, British Non-Ferrous Metals Research Association.

RAMMED LININGS FOR SMALL ELECTRIC FURNACES

By Henry C. Fisher
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Norton Company
Worcester, Mass.

IN THE August (1941) issue of METAL PROGRESS was discussed the general problem of selecting a refractory for melting and heating furnaces, and it was shown that the electric furnace products widely used as abrasives (such as fused alumina and silicon carbide) also had characteristics that marked them as superior refractories. In that article the molded refractories were considered, such as brick, tile, and tubes; it is now appropriate to say something of ramming mixtures in dry and semi-dry condition and the making of furnace linings therefrom.

Refractory ramming mixtures present a considerably different problem from shapes because more care must be used in their installation in order to get satisfactory results. We shall here omit a detailed discussion of heat insulation. We will also omit any discussion of wet ramming mixes, which are used in the plastic or semi-plastic condition. Their installation does not present the problems of the semi-dry materials.

Ramming material, as received by the user, consists generally of graded grain and bond. It may or may not contain sufficient water for ramming.

To obtain a maximum life from any refractory material, it must be rammed to maximum density. If open and porous, slag and metal will readily penetrate and mechanical erosion will be rapid; likewise a refractory material that does not shrink appreciably at furnace temperatures should be used. In fact, a small

permanent expansion is generally desirable.

Probably as good a way as any to describe the proper way of handling a ramming mix is to describe in detail the actual construction of typical furnace linings.

Lining a Rotating Furnace

The capacity of the furnace, shell dimensions, electrode diameter and materials to be melted must be known before the problem can be attacked. It will be assumed that these are known. To further simplify the problem, we will assume that the furnace is one of Detroit Electric Furnace Co.'s LF series and is used for melting nickel at 2900° F. The inner dimensions of the shell are 29 in. diameter by 29 in. long; the furnace chamber is to be 17 in. diameter by 17 in. long; the electrodes are 3 in. diameter. Such a furnace is shown in the photograph, Fig. 1. Cross-sectional views are sketched in Fig. 2.

A list of necessary equipment and tools follows:

1. Asbestos sheet, 17 ft. by 3 ft. by $\frac{1}{8}$ in. thick.
2. 100 refractory insulating brick or tile, 9 by $4\frac{1}{2}$ by 1 in.
3. Two fused alumina refractory sleeves, through which the electrodes pass.
4. 1200 lb. fused alumina ramming mixture.
5. Wood core 17 in. diameter, $16\frac{1}{2}$ in. long

(Fig. 3), made of $1\frac{1}{4}$ -in. pine, straight grained.

6. Cylindrical wood rod, 40 in. long by 3 in. diameter (Fig. 3).

7. Wood door frame (Fig. 3).

8. Ramming tools: A reciprocating hammer with a 1-in. square butt, and a butt with circular face 3 in. diameter.

Rivet hammer with two butts, one 1 by $2\frac{1}{2}$ in., the other $2\frac{1}{2}$ by $2\frac{1}{2}$ in.

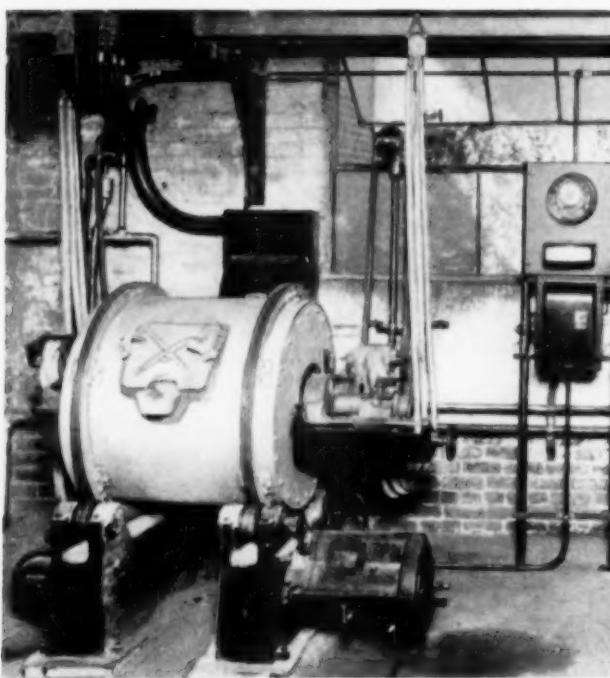


Fig. 1—Small Arc Furnace, Rocking Type, for Nickel Alloys (Detroit Electric Furnace Co.)

9. Heavy hack-saw blade.
10. Bar of strap iron sharpened at one end to form a chisel with a long bevel, $3\frac{1}{2}$ ft. by 2 in. by $\frac{1}{4}$ in.

Lining Procedure—Clean a place approximately 10 ft. square on a cement floor and dump all of the dry ramming mixture. Dampen it with $3\frac{1}{2}\%$ by weight of water. Mix by turning two or three times with shovels and then rub through a No. 6 mesh foundry riddle. Again turn the mixture on the floor and store in tight kegs or drums, covering the tops with damp burlap bags to prevent drying.

Remove one end of the clean furnace shell, set it on end with the open end up as shown in Fig. 3. It is well to set the shell on three-point supports and raise the bottom about 6 in. off the floor. This will provide working room under the furnace shell for centering the core.

Cut the asbestos sheet to fit the interior

bottom and side surfaces of the furnace shell, and put it in place, allowing it to overlap about 6 in. at the vertical joint. A hairpin of wire slid over the overlap and top of shell will keep the joint tight at the top and hold the asbestos sheet to the furnace shell.

Center the bottom electrode sleeve. Cut insulating brick to fit over the end circle on the asbestos sheet, and completely cover the bottom (the flat end of the furnace shell). These brick can be cut to fit radially, but it will be less work to fit them in straight and trim the corners. After the bottom has been covered, a lining of insulating brick should be put in place one course high (9 in. up) on the interior cylindrical surface. Rub the edges of these brick so that they will make tight vertical joints and slide in the last brick as a key to finish the circle. By using a little care here, it will not be necessary to cement the brick in place, and they will stay put during the ramming operation.

The rammed lining is to be approximately $1\frac{1}{2}$ in. thick, so plan to ram it in three layers. Distribute about $2\frac{1}{2}$ in. of the ramming mixture evenly over the bottom of the shell and ram in place with the reciprocating hammer, using the large butt. Go over this with the riveting hammer to insure a dense structure. Dig up the surface of the cement to a depth of approximately $\frac{1}{4}$ in. with the chisel before placing the succeeding layers.

The third layer should bring the lining up

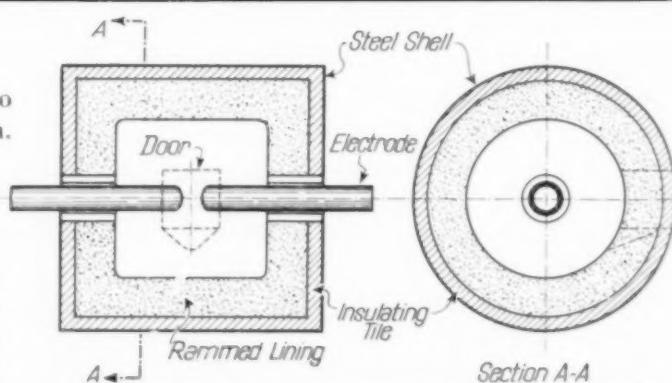


Fig. 2—Sketch Showing Essential Features

to the level of the furnace chamber. It is better to have this last layer a little thicker than desired and scrape off some material, than to find it necessary to build up to dimension with a thin layer of material, which may flake off after the furnace is in use and cause trouble.

After the bottom (really the end wall of the shell in its operating position) has been built up to the proper thickness, assemble the cylindrical rod and the chamber core as in Fig. 3. This shows a simple and at the same time effective method for holding the core in place. Two $\frac{5}{8}$ -in. holes have been drilled through the cylindrical rod at right angles to its length, the lower one being about 3 in. from one end, and the upper one being just above the top of where the wooden core will come. Get two $\frac{1}{2}$ -in. bolts or rods about 8 in. long. Assemble the cylindrical rod and core and insert one bolt in the bottom hole so that the ends project on each side of the bottom collar of the furnace shell. Insert the second bolt in the top hole and drive wedges between it and the upper end of the core. This will center the core and prevent it from lifting, when the lining is rammed.

After the bottom is in place and the core has been centered, dig up the exposed surface of the top layer of the rammed portion, and add about 1 in. of prepared refractory mixture. Use the reciprocating hammer with a small butt and ram the cement in place by going over the surface from four to five times. Make especially sure that the cement is rammed solidly next to the core. (The wooden core, of course, must be very stoutly built.) Add more cement and continue ramming without further scratching of the surfaces.

Lay up the insulating brick ahead of the ramming mix. When the bottom of the door has been reached, insert the door frame and ram cement around it. Keep the insulating brick back from the door face and ram cement in this space as shown in Fig. 3.

During the ramming operation it will be necessary to check the position of the core and wedge it back into position if it has moved sideways. Notice that a core $16\frac{1}{2}$ in. long has been recommended for a 17-in. chamber. This short length is necessary because the core will bend the bolts and rise approximately $\frac{1}{2}$ in. during the ramming.

When the top of the core is reached with

the rammed mixture, remove the top wedges and bolt, and ram in the material for the end, in the same way as done at the lower end. Ram cement to within $1\frac{1}{2}$ in. of the top of the shell, and over the top of the last layer fit the insulating brick, then the asbestos sheet, and finally put the steel end plate in place. Since the end plate fits inside the shell of the particular furnace under discussion, the insulation and lining mix must be held back at the end circumference to make room for the joint.

After the end plate has been bolted on, remove the cylindrical center rod, and burn out the wood core and door frame. When the furnace has cooled, cut in the rammed mixture to form the spout. Wherever necessary, a little ramming mixture made more plastic with water may be rammed in, at small patches, to smooth up the job.

Lining an Induction Furnace

As is well known, the widely used Ajax-Northrup high frequency induction furnace is ordinarily encased in a cubical box or frame. Essentially the furnace is an open topped crucible, tilting about its lip, the crucible being surrounded by a helical conductor carrying alternating currents at high frequency. Such conditions set up circulating currents in the metal contained in the crucible, and these currents convert their energy into heat.

The problem of lining such a furnace, therefore, is to construct a satisfactory crucible within the main coil, which as already noted is a helical coil of copper tube, water cooled during operation. Much of the practical information now to be given is due to J. A. SCOTT of the Driver-Harris Co., Harrison, N. J., and to G. F. LANDGRAF, until recently of the Lebanon Steel Foundry Co., Lebanon, Pa.

The crucible in the induction furnace is actually a separator between the charge and the primary coil. This separator must combine several properties such as electrical insulation, heat insulation, refractoriness, and chemical

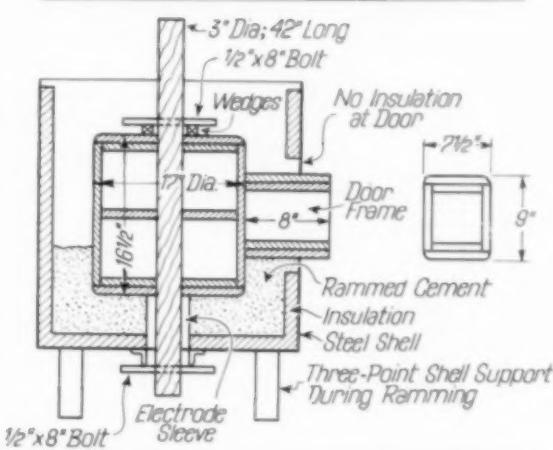


Fig. 3—Placement of Forms in Up-Ended Shell. Sketch shows lining partly rammed

inertness to the metals making up the charge and their oxides. The kind of refractory used—that is, whether acid, basic, or neutral—will be governed by the kind of charge to be melted and the kind of slag, if any, to be used on top of the charge.

Figure 4 shows the high frequency induction furnace in vertical and horizontal sections. The coil is firmly supported by vertical posts of asbestos wood or composition as shown at A.

The first operation is to plaster up the inner surface of the coil. For this purpose use a fine, dry cement similar in chemical composition to that to be used for the inner lining or crucible, 20 mesh and finer, of good workability, and mix to a medium plastic condition with sodium silicate and water (commercial water-glass) diluted with an equal

Fig. 4—Lining for High Frequency Induction Furnace

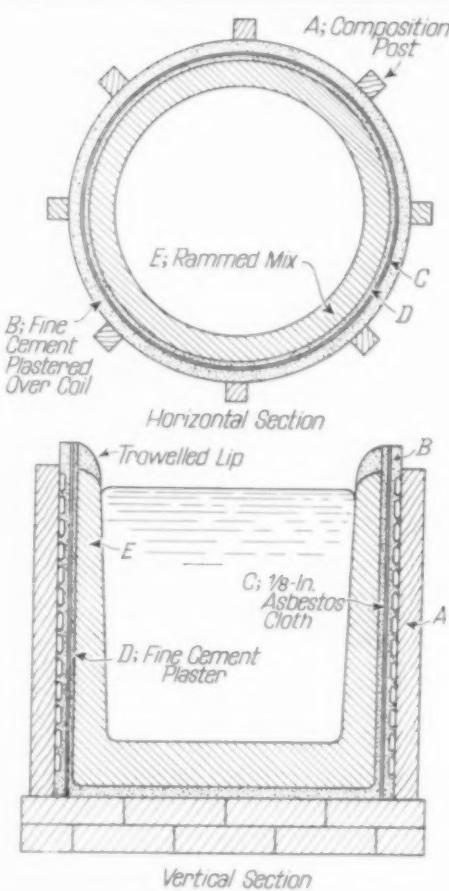


Fig. 5—Ajax-Northrup High Frequency Induction Furnace, Tilted While Pouring Molten Charge Into Waiting Ladle



volume of water). Work the mixture tightly against and between the successive turns of the coil. This cement layer, B in Fig. 4, should be between $\frac{1}{4}$ and $\frac{3}{8}$ in. thick over the coil.

Now moisten the inside surface of the cement layer with sodium silicate (commercial water-glass) and line with asbestos cloth, C, approximately $\frac{1}{8}$ in. thick.

Again moisten the inside surface of the asbestos cloth with sodium silicate and plaster on a second layer of cement, D, approximately $\frac{1}{4}$ in. thick, similar in composition to the first layer. It is well at this point to cover the bottom of the furnace with about 1 in. of the same cement, rammed well in place.

A total thickness of between $\frac{5}{8}$ and $\frac{3}{4}$ in. of lining has now been put in the furnace, whereupon the whole should be thoroughly dried by suspending two or three 100-watt incandescent lamps

inside the shell, loosely covering, and leaving for at least 24 hr.

If the lining up to this point has been carefully applied, four things will have been done:

1. A rigid support for the coil will have been obtained, and the coil will be held firmly in place.
2. Adequate protection of the coil against subsequent damage during the final ramming operation will have been attained.

3. A layer of cement in intimate contact with the coil will provide maximum cooling of the refractory by the cooling water in the coil. This last factor is of first importance if maximum life is to be had from the lining. At critical temperatures for a refractory, a lowering of the temperature of the refractory face of only 50° C. can readily mean the difference between success and failure. Chemical activity between the slag and the lining is accelerated with an increase in temperature.

4. The coil will be protected with a refractory material, not far different in chemical composition from that of the lining itself and having a degree of flexibility to minimize the tendency to crack.

After the plastic cement coating for the protection of the coil has dried, take the dry

material for the inner lining, *E* of Fig. 4, and put a sufficient amount in the bottom of the furnace to form a rammed bottom about 5 in. in depth. Ram thoroughly with a large rivet hammer fitted with a flat butt, employing the general technique already described for the arc furnace.

Now place a special cylindrical sleeve, made of "transite" for the purpose, in the furnace to form the crucible. Insert a wood core inside this sleeve for support. Ram the dry cement in layers solidly around the sleeve to a point approximately 1 in. above the metal line. This can best be accomplished by using the rivet hammer and a long flat tool. Work the dry cement thoroughly into place. Finish off the top of the crucible with the same kind of cement made plastic with water to which a small amount of sodium silicate has been added.

If time will permit, let the top layer of plastic cement dry before heating the furnace.

The wood core inside the transite sleeve should next be removed and the furnace charged for the first heat of metal. This heat will sinter a thin layer from $\frac{3}{8}$ to $\frac{1}{2}$ in. deep on the face of the crucible. At the same time it will flux away the transite sleeve. This fluxing action also assists in providing a glazed, impervious face to the crucible.

Assuming that the refractory has been properly chosen, good service should be expected. When the furnace cools, the sintered face may crack; however, these cracks will not extend back through the unsintered portion of the crucible lining and will not cause subsequent trouble. If properly installed, one outer lining should suffice for from three to four inner crucible linings.

LADLE COOLING OF LIQUID STEEL*

By T. Land

IT IS NOW POSSIBLE to control and measure with accuracy the temperature of liquid steel in the melting furnace, and thus it has become important to know what fall in temperature is to be expected between tapping and casting. The methods of calculating the drop in temperature (which may be 50 to 150° C. according to the ladle conditions) are explained in this report with mathematical formulas. The magnitude of the cooling is affected by the dimensions of the ladle, the physical properties of the refractory lining and the pre-heating that the ladle has received. A simple experiment with a model shows how the metal in the ladle cools by a relatively thin layer of metal passing down the vertical walls of the refractory lining and forming a reservoir of cool metal at the bottom of the ladle.

Some heat is lost through the brickwork to the shell of the ladle. However, calculations for a 25-ton ladle indicate that less than 10% of the heat absorbed at the hot surface has penetrated beyond $3\frac{1}{4}$ in. from the surface, when the time from tapping to finished casting is 40 min. The value of the thermal conductivity of liquid steel is not known with high accuracy and this is a major source of error in (*Continued on page 252*)

*Abstract of Paper No. 1, 1941, Steel Castings Research Committee, British Iron and Steel Institute.

Calculated Values of Loss of Temperature in Ladle Under Various Conditions

WEIGHT OF METAL CAST	TIME HELD IN LADLE BEFORE CASTING	TIME FROM COMMENCING TAPPING TO FINISHING CASTING	INITIAL TEMPERATURE OF METAL	PRE-HEATING TEMPERATURE OF LADLE	CORRECTION FOR LOSS OF TEMPERATURE	
					UNIFORM CASTING RATE	FREE FLOW FROM LADLE
40 tons	10 min.	53 min.	1620° C.	300° C.	110° C.	100° C.
"	5	40	1620	300	90	80
25	7	33	1620	400	95	85
"	5	40	1620	400	100	90
10	3	13	1620	600	65	60
"	3	13	1620	300	85	80
4 $\frac{1}{4}$	4	33	1600	700	125	110
2 $\frac{1}{2}$	3	12 $\frac{1}{2}$	1480	850	65	60
"	3	12 $\frac{1}{2}$	1480	650	85	80
$\frac{1}{4}$	1 $\frac{1}{2}$	3	1600	800	95	90
"	4	5 $\frac{1}{2}$	1600	800	135	130

EVALUATION OF THE DRAWABILITY OF THIN METALS

By Thomas F. Mika
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Victor Mfg. & Gasket Co.
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THIS ARTICLE will describe a practical production method developed for the evaluation of drawability of sheet metals by subjecting the metals to three operations — first a blanking, then a forming, and finally a closing operation.

Designed particularly for metals 0.0075 to 0.015 in. thick, the test method has been adapted to the evaluation of copper, brass, aluminum, steel, and other metals to be used for flanges, grommets, lips, and channels. It does not rely upon the interpretation of arbitrary values but rather gives a range of drawability which will work on a specific metal. The results may easily be expressed in actual per cent of draw.

We have also used the method to study the best annealing temperatures, proper order of operations, metal sources, proper press forming speeds, the evaluation of lubricants and die design. Above all, it gives us the limits we can work a specific metal. In view of the success achieved by us at Victor Mfg. & Gasket Co., it is probable that the simple equipment and methods to be described will be of assistance to other plants engaged in difficult sheet metal work.

Limitations of Cupping Tests — The various drawing or ductility tests in general use consider only the effect of a deep drawing operation. They measure the ability of the material to withstand and transmit the strain set up by the ball or the plunger used in the

testing machine. In an Olsen test, for instance, a ball, pushing against a flat piece of metal held rigidly in the jaws of the tester, merely measures the stretching of the metal during which thinning occurs. The more compound strains which occur in the drawing of a blanked edge, involving stretching, thinning of the metal, bending, and thickening of the metal, are not considered in the ductility tests like the Olsen, Erichsen, Avery or Guillory tests.

As remarked by JEVONS on page 250 of his book on "The Metallurgy of Deep Drawing and Pressing", "The limitations of Erichsen values as

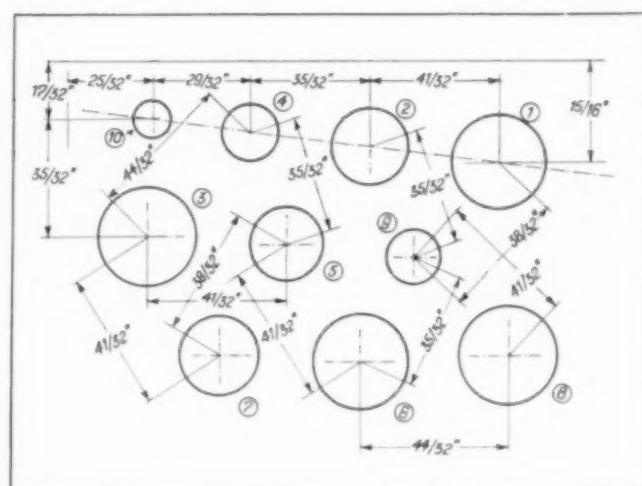


Fig. 1 — Location of Holes in Blanking, Draw and Closing Dies. Numbers refer to progression as to severity of draw; size of holes is only relative

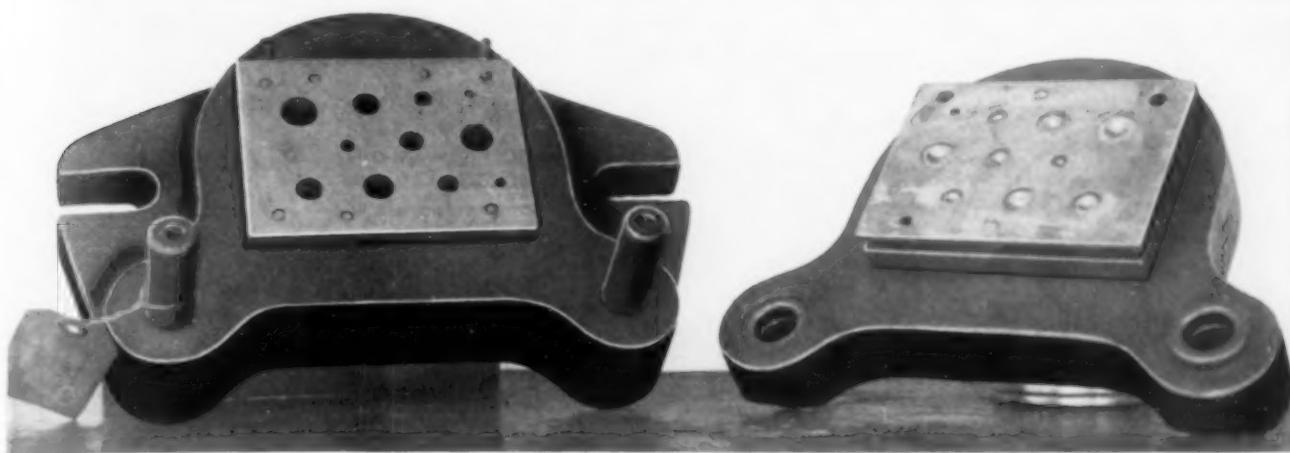


Fig. 2—Blanking Die

a reliable guide to the behavior of sheet metal under the press are rapidly becoming appreciated, and no better illustration of the fallibility of this test could be wished for than that provided by aluminum. The better behavior of the one-quarter hard ($\frac{1}{4}H$) and, in some instances, even half hard ($\frac{1}{2}H$) aluminum sheet under press tools is established quite definitely by both laboratory and industrial practical tests, yet the Erichsen values for the one-quarter hard, still more for the half hard sheet, are considerably lower than those for the fully softened, yet in practice inferior, sheet."

In an effort to evaluate metals which undergo more than the normal cupping operations, and whose elongation values in the ten-

sile test do not consider the stresses set up in the drawing operation as determined by the properties of the metal in the plastic range, a test has been devised to include all possibilities of three operations (*a*) blank, (*b*) form or draw, and (*c*) close. By means of three operations this test evaluates the blanking strains, the work hardening of the edges, cupping, bending, stretching, and thinning of the metal.

Materials and Procedure—A metal is evaluated in terms of the work it is to do. Because the metals in question are to be used in products which undergo a definite production cycle (blank to shape, form or draw to desired height, and close to desired thickness or shape), they are tested in the same way.

A sample of the metal to be evaluated (4 $\frac{1}{2}$ by 5 in. minimum, but more often 6 by 6 in.)

is blanked by a die so arranged as to give an increasing range of difficulty in draw. Figure 1 serves to illustrate the layout of the dies, and Table I lists diameters of the various holes formed during the test.

Sizes of the ten blanks or ranges of drawability chosen in this die test were determined by taking sizes most commonly encountered in gasket production. The blanks are so laid on the die test (as shown in Fig. 1) as to give a uniform distribution of drawing pressures

Table I—Dimensions of Die Tests and Character of Draw

HOLE (<i>a</i>)	DIAMETERS IN INCHES			DRAW		
	BLANK (<i>b</i>)	DRAW	CLOSURE (<i>c</i>)	HEIGHT	FACTOR (<i>d</i>)	PER CENT (<i>e</i>)
No. 1	0.718	$\frac{7}{8}$	$\frac{31}{32}$	$\frac{3}{16}$	.743	35
2	0.528	$\frac{11}{16}$	$\frac{31}{32}$	$\frac{3}{16}$	.676	48
3	0.658	$\frac{7}{8}$	1	$\frac{3}{16}$	.658	52
4	0.349	$\frac{1}{2}$	$\frac{7}{8}$	$\frac{3}{16}$	.621	61
5	0.472	$\frac{11}{16}$	$\frac{31}{32}$	$\frac{3}{16}$	.581	72
6	0.595	$\frac{7}{8}$	$1\frac{1}{16}$	$\frac{3}{16}$	.561	78
7	0.408	$\frac{11}{16}$	$\frac{31}{32}$	$\frac{3}{16}$	.484	106
8	0.528	$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{3}{16}$	.459	113
9	0.620	$\frac{1}{2}$	$\frac{7}{8}$	$\frac{3}{16}$	.448	123
10	0.151	$\frac{1}{8}$	$\frac{31}{32}$	$\frac{3}{16}$	.372	169

(a) Holes are numbered in Fig. 1, in order of increasing percentage of draw
(b) From approx. $\frac{3}{16}$ by $\frac{1}{16}$ -in. increments to $\frac{11}{16}$ in.

(c) Outside diameter of flange after closure:

(d) Draw factor is ratio of blank diameter (*b*) to diameter of closure (*c*)

(e) Computed by the formula $\frac{(c)-(b)}{(b)} \times 100$

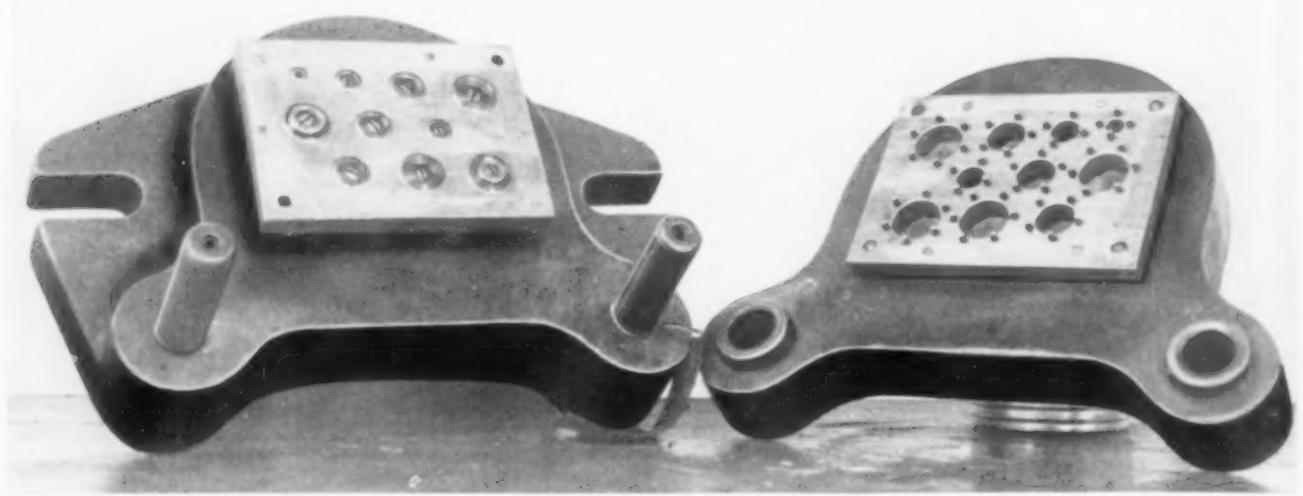


Fig. 3 — Forming Die

within the smallest surface area. The numbers and arrangement in the table are in accordance with the increasing difficulty or percentage of draw. If the holes in the dies were arranged consecutively in order of size or order of draw they would cause non-uniform distribution of drawing pressures and would have to be spread over a larger area.

Dimensions of the dies and of the product are listed in Table I. The blanking die is shown in Fig. 2, and it will be apparent that a blanked test piece contains a series of holes ranging from about $\frac{5}{32}$ to $\frac{35}{32}$ in increments of $\frac{1}{16}$, as listed more accurately in column 2 of the table.

After blanking the test piece is subjected to the action of a forming or drawing die (illustrated in Fig. 3). The upper part of Fig. 5 shows a blanked $4\frac{1}{2}$ by 5-in. sheet, 0.010 in. thick, and the lower part shows the same after the second or drawing operation. The degree of forming or height of draw for each hole is listed in column 5 of Table I.

Closing Operation — Over the projections of the formed test piece are placed two fillers or spacers, fitting fairly tightly over the collars. The first is made of a previously blanked sheet of 0.050 to 0.055-in. asbestos millboard, and the top filler is made of a previously blanked 0.007-in. steel. Both of these fillers are blanked to the same diameters as the projections of the drawn test piece, and are placed on

the test piece in order to form a uniform surface over which the upstanding collars may be closed. The fillers are chamfered or bent down slightly at their inner diameters to give a uniform curvature of the closure, as normally encountered in this type of production.

The drawn test piece, over which have been placed the two fillers, is finally subjected to a closing operation in the die shown in Fig. 4. The degree of closing is so regulated as to give a range of diameters as listed in column 4 of Table I. The degree of closing may be controlled by the fillers and the extent to which the closing dies are lowered.

Table II — Average Drawability of Non-Ferrous Sheet (a)

METAL	TYPE	DRAW TEST		OLSEN DUCTILITY
		HOLE	PER CENT	
2S Aluminum	Dead soft	3	52	0.289 to 0.282
	Soft	3	52	0.276 to 0.270
	$\frac{1}{4}$ H	5	72	0.272 to 0.266
	$\frac{1}{2}$ H	6	78	0.252 to 0.246
Brass	$\frac{1}{4}$ H	2	48	0.222 to 0.219
Bronze	Dead soft	4	61	0.342 to 0.329
Cadmium	Dead soft	6	78	0.396 to 0.392
Copper	Dead soft	4	61	0.365 to 0.360
Magnesium	Dead soft	none	—	0.126 to 0.120
Monel	Dead soft	2	48	0.444 to 0.439
Nickel	Dead soft	2	48	0.335 to 0.331
18% nickel silver	Spring hard	none	—	0.200 to 0.196
Tin	Dead soft	10	169	0.403 to 0.396
Zinc	Dead soft	5	72	0.359 to 0.355

(a) Conducted on 6 by 6-in. samples of 0.010-in. sheet as received from the mill, and tested in a manner comparable to the simplest production cycle.



Fig. 4—Closing Die

To eliminate the differential that may arise with the lubricating effects of various oils on different metals, all test pieces and dies are solvent degreased before any tests are started.

After test pieces are closed they are visually examined to determine what holes have been drawn successfully. The extent of drawing may be expressed as a range, that is, as "passed holes 1 to 5", or may be expressed as the maximum hole drawn, that is, "fifth hole". The holes successfully drawn may also be expressed as a draw

factor or as the per cent of draw, as indicated in the footnotes to Table I.

Figure 6 illustrates good and bad drawability as determined by the die test. The picture on the right shows drawability to the ninth hole (disregarding the slight evidence of failure

on hole No. 8) while the picture on the left shows slight edge cracking on the first hole. Both of these are in red brass sheet. Table II illustrates the maximum drawability that various metals may be drawn, as shown by general experience with our die test. It is important to note that high Olsen values do not necessarily mean good drawability—but this

Table III—Relation of Grain Size of Copper to Drawability (a)

GRAIN SIZE, MM.	DRAW		OLSEN DUCTILITY (b)
	HOLE	PER CENT	
0.015	7	106	0.380 to 0.375
0.020	6	78	0.378 to 0.373
0.025	5	72	0.376 to 0.372
0.030	5	72	0.361 to 0.350
0.035	4	61	0.358 to 0.350

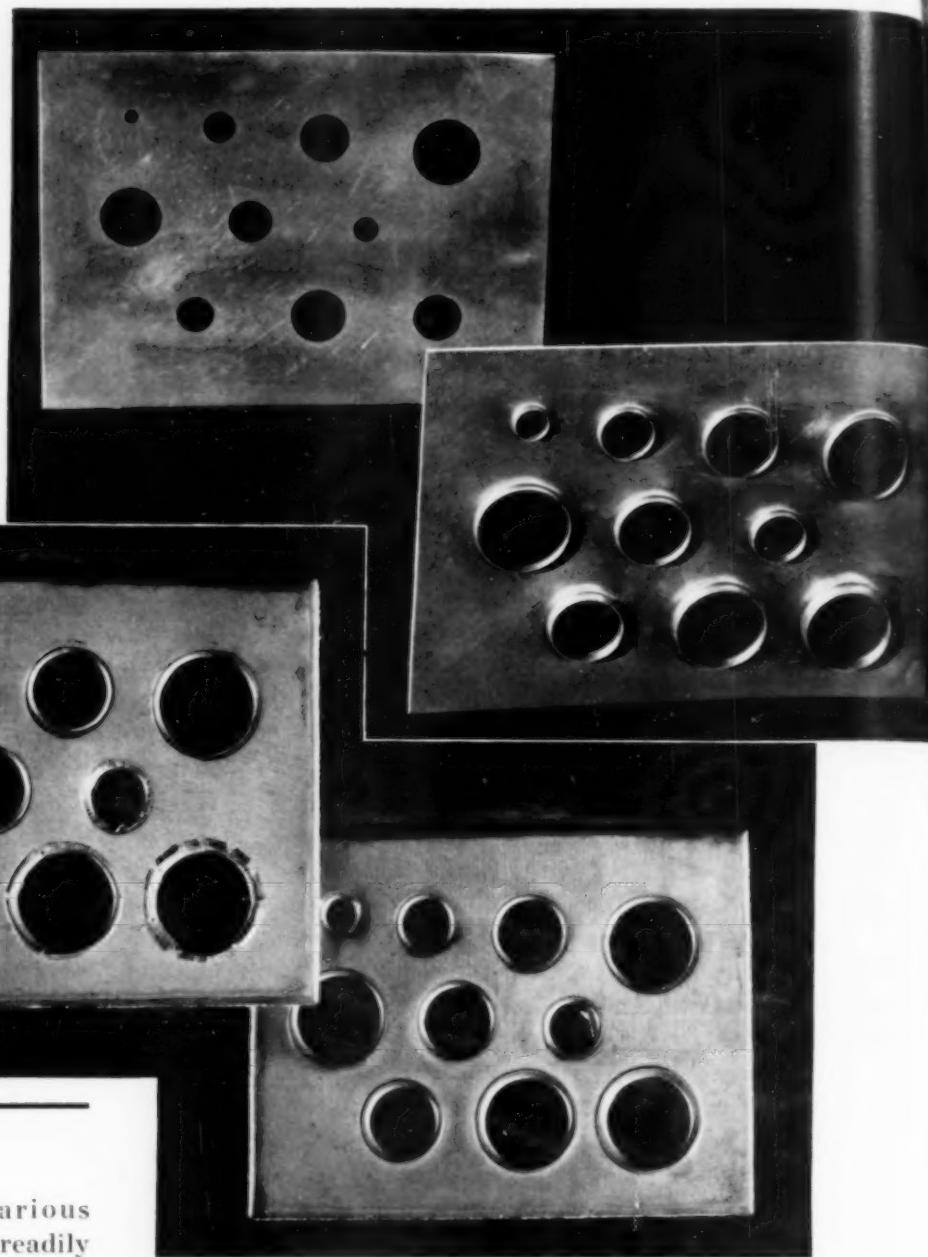
(a) Copper received from the mill with the grain size specified was blanked, annealed at 1100° F., formed, re-annealed at 1100 and closed.

(b) As received from the mill.

Table IV—Drawability of Lead Alloys; 0.010-In. Sheet; Mill Run

MATERIAL	ANALYSIS				DRAW TEST		OLSEN DUCTILITY
	Pb	Sn	Sb	Cu	HOLE	PER CENT	
Sheet lead	99.9				3	52	0.315 to 0.310
Tellurium lead	99.1				5	72	0.290 to 0.281
Antimony lead	94		6		2	48	0.270 to 0.266
No. 170 refrigerator	91	6	3		2	48	0.280 to 0.276
No. 160 refrigerator	81	10	8	1	1	35	0.275 to 0.266
No. 150 refrigerator	72	20	6	1	none	—	0.280 to 0.273
No. 8 Hoyt metal	46	46	8		1	35	0.270 to 0.264

Fig. 5—Test Sheet After Blanking (Top, Left) and Drawing (Below, Right). The drawing operation was successful down to and including hole No. 6; No. 7 (at lower left) is cracked at edges of the collar



indeed, is no new fact.

Annealing—Because various metals like stainless and monel readily work harden, it has been found more significant to anneal the test pieces after each operation. The routine would then be blank, anneal, form, re-anneal, and finally close. Figure 7 shows the effect of various annealing temperatures on the drawability of electrolytic and lake copper as determined by this test. The question of time of anneal, temperature of anneal, type of atmosphere, and type of quench may also be readily determined by this test, particularly where a definite per cent of draw is required of a specific metal. If a user is annealing brass at 900° F. in a reducing atmosphere for 1 hr. per in. of thickness followed by a water quench, and it is desired to get the best source of brass,

Fig. 6—Completed Test on Two Samples of Red Brass, After Closure Over Fillers of Asbestos Millboard and 0.007-In. Steel. At left is poor sheet that shows incipient edge cracking at hole No. 1 (upper right corner), and at right below is an excellent sheet that forms perfectly up to hole No. 6 (middle bottom)

the tests would be run on this specific production cycle.

As pointed out by Gwyer and Varley in their study of deep drawing tests on aluminum reported in METAL PROGRESS, March 1936, p. 82, "The drawing quality of the samples examined bore no relation to the Erichsen value or the elongation in the tensile strength test. Although

the medium tempers gave much lower values for these two properties than did the soft temper material, they are not markedly inferior in drawing quality, as might have been expected, but actually withstood a much heavier draw

Table V — Drawability of Steels; 0.010-In. Sheet; Mill Annealed

TRADE NAME	NATURE	DRAW TEST		OLSEN DUCTILITY
		HOLE	PER CENT	
iron	Electrolytic	5	72	0.382 to 0.376
Armco iron	Openhearth	6	78	0.380 to 0.375
bessemer steel	Pickled black plate	none	—	0.260 to 0.256
soft steel	Openhearth	5	72	0.305 to 0.300
Tin plate	Openhearth (1010)	5	72	0.326 to 0.320
ferne plate	Openhearth (1010)	7	106	0.329 to 0.319
Copper plate	Electroplated 1010	4	61	0.306 to 0.300
Aluminum plate	S.A.E. 1045	4	61	0.240 to 0.236
Allegheny metal	18-8; 0.20% C	2	48	0.241 to 0.236
Allegheny No. 55	(a)	none	—	0.209 to 0.201
Allegheny No. 66	16% Cr, 0.12% C	1	35	0.238 to 0.233
Cyclops No. 17	(b)	2	48	0.255 to 0.230
Enduro KA2	18-8; 0.15% C, 0.75% Si	5	72	0.271 to 0.264
RA Ludlum	(c)	5	72	0.285 to 0.278

(a) 25 to 30% Cr, 6% Ni, 1.0% Mn, 0.6% Si, 0.35% C

(b) 7.5% Cr, 20% Ni, 0.75% Mn, 1.0% Si, 0.45% C

(c) 16.5% Cr, 0.93% Cu, 0.4% Mn, 0.71% Si, 0.06% C

in the second operation. Further, although samples of soft sheet have almost identical mechanical properties, the difference being within experimental error, they showed, on test, quite different drawing properties." This same characteristic has been found in our work with the three-stage die test, as shown in the top lines of Table II, giving the comparative Olsen values and die test values on various hardnesses of commercially pure aluminum.

In the normal cupping tests the influence of speed of drawing is often forgotten, or the rate of deformation is so slow that the tests have no correlation to industrial press operations. By the use of a crank press MATHEWSON, TREWIN and FINKLEDY have shown the great importance of high speed cupping tests. (See "Some Properties and Applications of Rolled Zinc Strip and Drawn Zinc Rod", *Transactions, American Institute of Mining and Metallurgical Engineers*, 1920, p. 305.) The test procedure described by the present author is readily adaptable to varia-

tions in speed of drawing. By varying the diameters of the pulley on the press drive, or by varying the speed of the motor in the case of direct drive, speeds from 0.20 to 150 ft. per min. have been obtained. The procedure not only permits duplication of actual production drawing time but also serves to determine the best rate of draw to obtain a specific per cent of draw on a specific metal. ☐

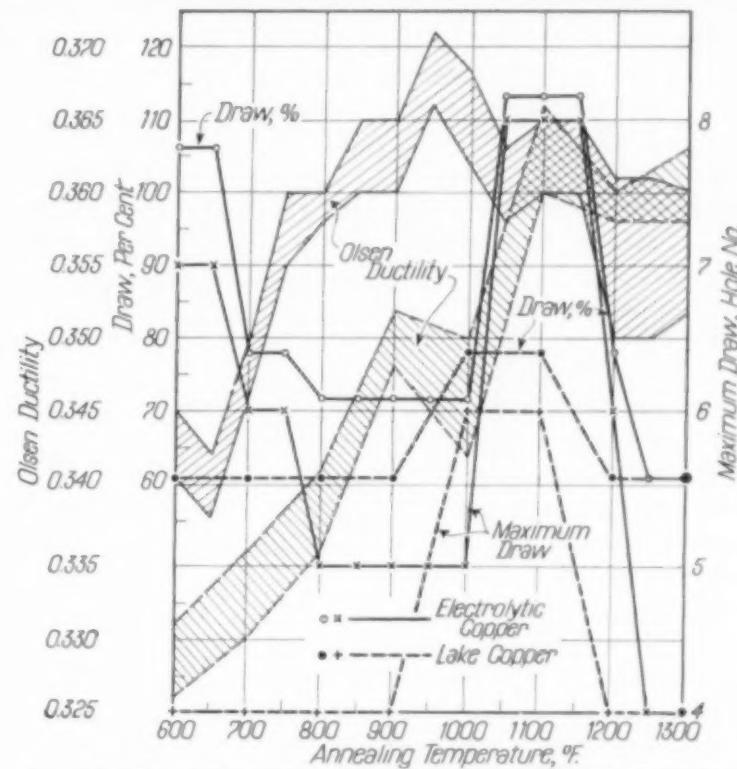


Fig. 7—Effect of Annealing Temperature on Drawability of Copper. The "electrolytic" copper contained 0.027% oxygen and 16 oz. silver per ton; and the "lake" copper 0.043% O₂ and 8 oz. Ag. Original sheet was 0.010 in. thick, half hard. Each annealing was 1 hr. long in neutral atmosphere in a muffle furnace. Cycle was: Anneal, water quench, blank, re-anneal, quench, form, re-anneal, quench, close

CONFUSION IN TESTING TERMS AND METHODS

By George P. Lenz, Jr.

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IN 1917, D. K. BULLENS stated in his valuable book "Steel and Its Heat Treatment": "The term 'elastic limit' has probably been more ill-used than any other common technical testing name, with the possible exception of hardness." This statement, unfortunately, can be quoted in 1942 without exaggeration.

The definition of the "elastic limit" as stated in the American Society for Testing Materials Standards, 1939, is "the greatest stress which a material is capable of developing without a permanent deformation remaining upon complete release of stress". In the practical determination of such an elastic limit the limiting factor is the part of the definition requiring "complete release of stress". While the operation is probably possible in scientific research, the writer does not know of any type of practical testing machine or practical extensometer with which such a true elastic limit can be determined. The majority of commercial testing machines require a small load to set the grips and most of the extensometers now used in industrial laboratories are not attached to the specimen until a small load has been applied. For all practical purposes the determination of the A.S.T.M. elastic limit is beyond the scope of an industrial laboratory.

A more common view (and unstated definition) is that the elastic limit is the working strength of the material. Inasmuch as the true elastic limit is very difficult to determine, and also that it is quite necessary to know the working strength of the material as defined by its

elastic behavior, other terms and methods of determination have been invented to give various degrees of approach to the value of the true elastic limit as defined by the A.S.T.M.

The addition of these new terms has added to the confusion and mis-use that seemed to be prevalent as long as a quarter of a century ago. It cannot be said that these new terms are not well defined or that the methods of determination are variable, because the latest Army and Navy specifications as well as the A.S.T.M. specifications are very much in agreement as to definition and method of determination. Such being the case, what causes the confusion — or let us say, mis-use — of these new testing terms and their determination? The author believes that in the majority of cases it is due to the misapplication of the particular test procedure to the type of material, inasmuch as each of these new tests was developed for a metal or alloy in a definite physical state.

It is general knowledge that the stress-strain curve of hot rolled material differs considerably from the curve of cold worked material, and that the stress-strain curve for heat treated material varies considerably from both. This is illustrated in the first figure. In view of the undoubted excellence and adaptability of steel in all four of the indicated conditions, it is obviously necessary to have different methods for determining their working strength. It is

possibly possible to apply several of these methods and terms to the same physical state, but the particular value that is required should be the figure that is used by the designer, and controls his computations. Here we come to another step in the confusion of terms, and, the author believes, a place where considerable improvement can be made. It is very possible that the person who sets up the specification writes "elastic limit" when he really means "yield point", or possibly he says he wants the "proportional limit" when the design is really figured on a "yield strength" value.

The correlation of these testing terms as to their position on the stress-strain curve may help in straightening out this confusion. This will now be attempted.

It has already been said that the determination of the true elastic limit is beyond the scope of ordinary testing equipment. This brings us to the closest practical approach, namely the proportional limit.

According to the A.S.T.M. Standards for 1939, Part I, Metals, p. 778, the proportional limit is "the greatest stress which a material is capable of developing without a deviation from the law of proportionality of stress to strain". (Hooke's law states that, below the elastic limit, the deformation produced is proportional to the stress.) There are two commercially practical ways to determine the proportional limit. First, and most satisfactory, is the use of an autographic stress-strain recorder. This will draw a curve from which you can determine the proportional limit by laying a straight-edge along the straight, or proportional, part of the curve, and thus approximate the position at which the recorded curve deviates from the straight line. In the second method this value can be found with an extensometer. With the extensometer attached to the specimen, the load is applied and corresponding readings of strain (stretch) and stress (load) are recorded. Either equal increments of stress

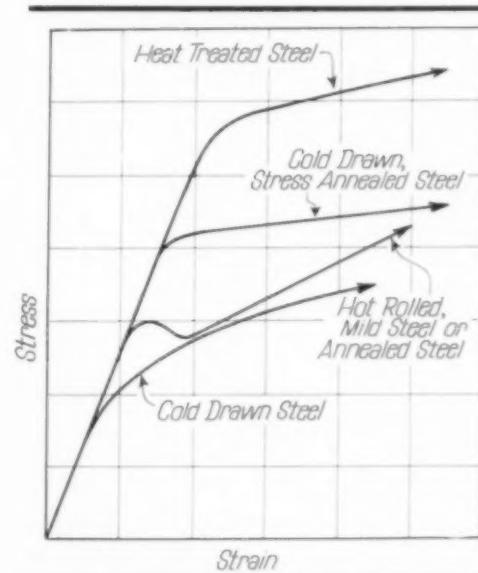
or strain should be used, depending on which is the easier to control. This will give the necessary points to plot the stress-strain curve, thus making it possible to determine the proportional limit. A fair idea may be had from inspection of the results: If the load is increased by 2000-lb. steps, the specimen will elongate by equal amounts until the proportional limit is passed. The term "proportional limit" is a good one for it defines itself.

The proportional limit can only be determined on those materials having a portion of the stress-strain curve which is a straight line. Otherwise there is no proportionality between stress and strain, and no proportional limit. Hot rolled, annealed, heat treated, or stress annealed steels possess a proportional limit. Inasmuch as cold worked material does not follow Hooke's law of proportionality, the term proportional limit should not be applied to it. This also eliminates any tests on cold worked material whose interpretation requires that a parallel line be drawn to the region of proportionality, as in offset methods. Cold worked materials must be stress annealed in order that test samples may show a region of proportionality in the stress-strain curve. One other assumption is commonly made, that the modulus of elasticity is not changed by work or heat treatment, so a sloping straight line plotted according to this assumption is sometimes drawn to indicate a supposed condition of proportionality.

This brings us to the next closest approach to the true elastic limit, the proof stress, which is applicable to materials in all physical conditions, but is in most cases applied only to those materials having a region of proportionality in their stress-strain curves. Otherwise, very low values are obtained for useful materials whose stress-strain curve is straight for

only a very short distance from the origin.

"The proof stress is that load per square inch of original cross-section which a material is capable of withstanding without resulting in a permanent elongation of more than 0.0001 in. per in. of gage length, after complete release of



Initial Portion of Stress-Strain Diagram for Steels in Various Conditions

load." This is quoted from the "General Specifications for Inspection of Material", Appendix II, U. S. Navy Department. Here again we note that *complete* release of load is specified, and this allows the concept of proof stress to be usefully extended to the testing of completed units or even structures. In actual tensile test practice it is customary and permissible to start with a small load on the test piece, set the extensometer at zero at that load, and release the additional loads each time down as far as the *original* load.* Because of the great number of autographic stress-strain recorders now in use, deviation from the standard release-of-load method is sometimes permitted on materials that draw a proportional or straight early portion of the stress-strain curve. When the load is released the tracing pencil does not retrace its original path, but comes back toward the horizontal axis in a fairly straight line, parallel to the slope of the line representing the modulus of elasticity. The alternative method is to draw the stress-strain curve, autographic or from plotted points, then draw a parallel to the proportional portion of the curve at an elongation of 0.0001 in. per in. of gage length. Where the parallel line intersects the stress-strain curve is the value for the proof stress. The scheme is shown on the second diagram.

This test method also provides a means of determining the "yield strength" as defined in "General Specifications for Inspection of Materials", Appendix II, U. S. Navy Department: "The yield strength is the load per square inch of original cross-section at which a material

*It may be well to mention that there are specifications which actually require the determination of what is called the "elastic limit" in manner similar to the proof stress method, with the exception that a permanent deformation of only 0.00003 in. per in. of gage length is permitted. This requires an accurate extensometer with divisions reading in not less than 0.00002 in. and an instrument this exact is seldom found in industrial laboratories.

exhibits a specific limiting permanent set or specified elongation under load." It is possible that the term and method were invented either to apply to metals which do not yield suddenly (as later to be defined) or to give a more precise meaning to definitions of that same yield phenomenon. At any rate, as can be deduced from this definition, the yield strength of a material can be any one of an unlimited number of values depending entirely on the permanent set noted in the specification or agreed upon by the respective parties, and on the method used in the laboratory for obtaining the value from the given set.

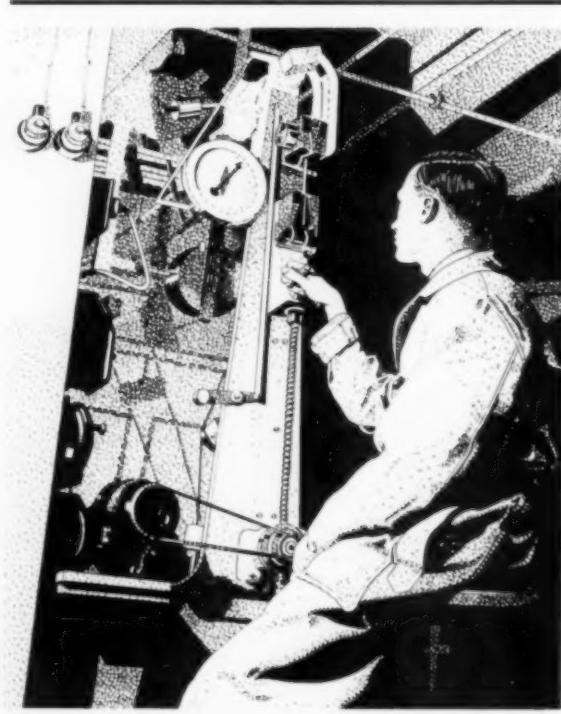
In fact, the definition covers two different methods of obtaining the yield strength. One is by the so-called offset method which requires a stress-strain curve, one portion of which is proportional. The other method is the extension-under-load method which requires the use of only an extensometer.

These two methods, using the same value for deformation, can give widely varied values.

It is certainly apparent that this definition is not definite enough; it covers too many methods and values. While both test methods (offset and extension) have merit if applied correctly, it is important to state definitely what method is to be used. In the offset method, a line is drawn from the specified deformation parallel to the region of proportionality, whereas the extension-under-load method requires that a line be drawn from the deformation specified perpendicular to the strain axis. As a matter of fact, the latter method does not require

a stress-strain curve; with the extensometer on the specimen, the load is read at a given "set", as indicated by the extensometer.

It is obvious, therefore, that whenever specifications are imposed on a material calling for "yield strength" the exact method for its determination must be included.



This brings us to the furthest approach to the true elastic, and probably the most mis-used, interpreted, and most commonly determined value, the "yield point". In defense of the author's strong statement is this quotation from the A.S.T.M. Standards for 1939, Part I, Metals, page 779: "It should be noted that only mate-

ods giving the same values but identified by different terminology.

The yield point, as defined, can be determined on hot rolled and annealed materials by the drop-of-beam method or the divider method. When using the drop-of-beam, the operator applies the load at a rate sufficient to keep the weighing beam balanced. At the yield point the beam will drop and remain down for a short interval of time. The beam will then rise, indicating that further loading is necessary to balance it again. With the divider method, the operator holds a pair of dividers firmly in one punch mark and notes the load at which the other end of the divider leaves the other punch mark due to the sudden and fairly rapid elongation of the test piece.

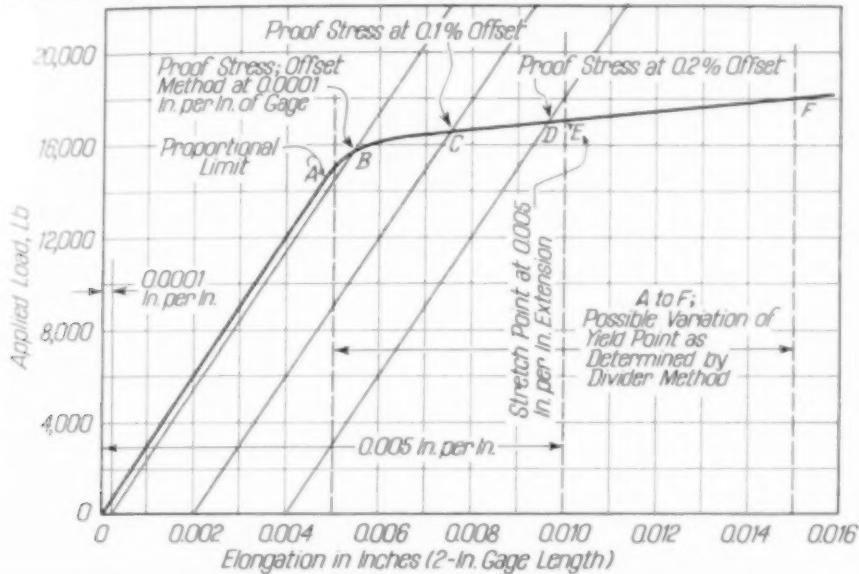
This divider method for obtaining yield point has been applied to materials of every physical condition. Inasmuch as the human element is the controlling factor, the yield point so determined is subject to a great deal of variation.

It has been found that even

experienced operators call yield points at elongations under load of from 0.005 in. to 0.015 in., depending on the type of material and its physical condition. Of course, this value may be close enough for the use and the factor of safety, but it will undoubtedly cause considerable and unnecessary trouble in comparative testing for acceptance.

To summarize these arguments the second figure plots a representative stress-strain curve of cold drawn, stress annealed steel. On it are shown the values obtained by above described methods for proportional limit *A*, proof stress by the offset method *B*, yield strength for both 0.1% offset *C* and 0.2% offset *D*, yield point *E* as determined according to both Army and Navy specifications of 0.005 in. per in. of gage length extension under load, and the range *A* to *F* of yield point obtained by the divider method.

The author would now like to advance a few ideas concerning the application of these various terms and also to suggest terms and



Typical Stress-Strain Diagram (Enlarged Horizontal Scale) for Cold Drawn Steel After Stress Annealing, Showing How Various Values in the Region Between Elastic Action and Plastic Flow Are Defined

rials that exhibit this unique phenomenon of yielding have a yield point. The term, yield point, should not be used in connection with material whose stress-strain curve in the region of yield is a smooth curve of gradual curvature." This limits the application of the term "yield point" to soft steel in the hot rolled or annealed condition.

The definition of yield point, namely, the stress on a material at which there occurs a "marked increase" in strain without any increase in stress, certainly lacks precision. The question arises as to what constitutes a marked increase in strain. Further, the various specifications, even though they state the definition of the yield point as above, go on to describe offset and extension-under-load methods for determining the "yield point". These methods are definitely defined under yield *strength* determinations, and therefore testing engineers are confronted with the amazing situation wherein we have two terms, yield strength and yield point, which can be obtained by the same meth-

definitions that should be retained and those that should be eliminated.

The terms "proof strength" and "yield strength" should be clearly separated. Proof strength should be measured by a line drawn at the slope of the modulus of elasticity for the material under test.

The use of the term "yield strength" should be discouraged in any other connotation than the "yield" of a soft steel which occurs shortly beyond the limit of proportionality.

The extension-under-load method, now permitted by the yield strength definition, defines positions so far beyond the true elastic limit and the limit of proportionality as to be in the region of permanent set or stretch, and therefore might determine the "stretch point" (a new term but a distinctive one).

For a more accurate determination of the working strength of hot rolled, annealed, heat treated, or stress annealed materials (carbon steel and alloy steel) the proportional limit is the most satisfactory.

The author advocates definitions and practices as follows:

Proportional Limit — Definition: The greatest stress that a material is capable of withstanding without a deviation from the law of proportionality of stress to strain (Hooke's law). Method of Determination: Obtain a stress-strain curve either by an autographic recorder or by obtaining the points for the curve by an extensometer, and extend the proportional (straight) region of curve to determine the place where the stress-strain curve ceases to be proportional.

Proof Strength — Definition: The greatest stress at which a material exhibits a specific limiting permanent set. Method of Determination: Obtain a stress-strain curve and draw a line parallel to the region of proportionality from the point on the strain axis marking the specific limiting strain. The intersection of the stress-strain curve and the drawn line will give the value for computing yield strength.

Stretch Point — Definition: The greatest stress at which a material exhibits a specified elongation under load. Methods of Determination: 1. Obtain a stress-strain curve and draw a line perpendicular to the strain axis from the given point of specified elongation. 2. With the extensometer on the specimen apply load and read the load required to give the specified elongation as read on extensometer.

Yield Point — Definition: The stress on a material at which there occurs a marked

increase in strain without any increase in stress. Methods of Determination: 1. Apply load at a rate sufficient to keep beam in balance; at the yield point the beam will drop, indicating an extension without increase in stress. 2. Punch mark specimen for desired gage length, hold dividers firmly in one punch mark, apply load and note the stress at which the free end of dividers leaves its punch mark.

Limitations of Determinations

Application of above terms will be approximately as follows:

Proportional limit, for accurate determination of working strength* on hot rolled, annealed, heat treated, and stress annealed materials.

Proof strength, for determining the working strength or safe overload of hot rolled, annealed, heat treated and stress annealed materials at a specified but small permanent deformation.

Stretch point, for determining the working strength of materials in all physical conditions at a specified elongation under load. This is the only determination that can be used on cold worked materials that are not stress annealed.

Yield point, for easy determination of the working strength of hot rolled and annealed low carbon steels.

The author realizes that to advocate changing all present specifications is out of the question, but he believes that if every new specification set up states the exact values desired and the method of determination, there will be a considerable relief of the present confusion. As an example, if it is necessary to obtain a material with a working strength of 70,000 psi. and it is understood that a permanent deformation of not more than 0.1% is not objectionable, the specification should be set up as follows:

Proof strength, 70,000 psi. by the offset method at 0.1% of gage length.

Another example would be a requirement necessitating a cold worked material with a working strength of 90,000 psi. with a maximum elongation under load of 0.005 in. per in. of gage length. The specification should be set up as follows:

Stretch point, 90,000 psi. giving no more than 0.005 in. per in. extension under load.

*By "working strength" the author means a figure that can be safely related to the unit stresses permitted in the design, or actually endured (even locally and repeatedly) in service.

Fluxes for Oxy-Acetylene Welding & Brazing

By Houston E. Landis, Jr., and F. C. Saacke

Apparatus Research & Development Dept., Air Reduction Sales Co., Jersey City, N. J.

General Flux Characteristics

Phase — Best applied to welding rod as a paste (suspension of powdered salts in water or alcohol). Sometimes applied as a dry powder or injected as a vapor into the welding atmosphere.

Melting Point — Below temperature where an appreciable amount of oxide forms on base metal.

Film — Uniform, quiescent, transparent.

Density — Light and easily floated; no tendency to be trapped in weld metal.

Viscosity at Welding Temperatures — Should be sufficient to keep the weld metal covered and protected from gas absorption and oxidation, but not so viscous as to prevent ready fusion of the welding rod and weld metal.

Oxide Solvent — Should readily dissolve base metal oxides as well as weld

metal oxides and keep contact surfaces clean at welding temperatures. (Base metal should practically always be cleaned before welding.)

Weld Appearance — All the above characteristics should combine to permit the rapid deposition of a weld free from oxides, flux inclusions, or gas pockets with smooth, clean surfaces free from overlaps or pits.

Oxy-Acetylene Welding Procedures

BASE METAL	FUSION WELDING				BRAZING		
	FILLER METAL	FLAME (a)	FLUX	FILLER METAL	FLAME (a)	FLUX	
Lead	Same as base metal	N	None	...	...	...	...
Aluminum (soft)	Same as base metal	SR to N	Type A	Aluminum solder	N or R	None	None
Aluminum alloy (wrt.)	Same as base metal	SR to N	Type A	Aluminum solder	N or R	None	None
Cast aluminum	Silicon-aluminum alloy	SR to N	Type A	...	...	...	...
Yellow brass	Silicon-aluminum alloy	SR to N	Type B	...	...	...	...
Red or leaded brass	Similar to base metal	O	Type C	Silver alloy or phos-copper	SR to N	Type H	Type H
Silicon bronze	High zinc brass (b)	N	Type C	Silver alloy or phos-copper	SR to N	Type H	Type C
Copper	Similar to base metal	N to SO	Type C	High zinc brass (b)	SR to N	Type H	Type H
Nickel	Deoxidized copper	N	None	Silver alloy or phos-copper	N to SO	Type C	Type C
Nickel-copper alloy	Same as base metal	R	None	High zinc brass (b)	SR to N	Type H	Type H
Nickel-copper alloy	Same as base metal	N to SR	Type C	Silver alloy	SR to N	Type H	Type H
Nickel-copper alloy	Silicon-monel	N to SR	None	Silver alloy	SR to N	Type H	Type H
Cast iron	Similar to base metal	N	Type F	High zinc brass (b)	N to SO	Type E	Type E
Malleable iron	White cast iron (c)	N to R	Type F	High zinc brass (b)	N to SO	Type C	Type C
Galvanized iron	...	..	..	High zinc brass (b)	N to SO	Type C	Type C
Carbon steel	Low carbon steel	N	None	High zinc brass (b)	N to SO	Type C or D	Type C or D
Alloy steel	Low alloy steel	SR	None	Silver alloy	SR to N	Type H	Type H
Stainless iron & steel	Similar to base metal	SR	None	Silver alloy	SR to N	Type H	Type H
High manganese steel	Similar to base metal (d)	N	Type G	Silver alloy	SR to N	Type H	Type H
	Similar to base metal	N to SR	None	...	...	...	...

(a)

N—Neutral

O—Oxidizing

R—Reducing

SR—Slightly reducing

SO—Slightly oxidizing

(b) High zinc (38 to 44%) brass with additions of alloying elements such as tin, iron, manganese, silicon, nickel.

(c) Fusion welding of malleable iron should be followed by re-malleableizing heat treatment.

(d) 18-8 stainless steels often alloyed and "stabilized" with columbium, titanium, molybdenum, tungsten.

Specific Flux Characteristics

Aluminum Rod

Type A — An aluminum welding flux composed generally of alkali halides; characterized chiefly by the speed with which solid welds in sheet metal may be made with smooth fusion at the root of the weld and without pitting or discoloration on the surface.

Type B — A modified aluminum welding flux with additions of higher melting point constituents like borates and other chemicals to provide greater slagging action as well as additional viscosity, resistance to oxidation, and protection while making repairs in cast aluminum parts by puddle welding.

Bronze Rod

Type C — An "oxidizing" flux ordinarily made with a boric acid base. It should form a thin but strong oxide film on the surface of the molten copper

alloy, thereby preventing gas absorption and excessive oxidation. Recommended for clean or cleaned iron and steel surfaces.

Type D — Where oxidized, rusty, or dirty surfaces are to be joined, an "oxide solvent" flux ordinarily made with a borax base and having a high solvent action for metallic oxides is recommended. It should keep both the base metal and the molten puddle clean and bright. (Note: This flux will not give as good weld metal characteristics as the Type C flux applied to clean surfaces.)

Type E — A "highly oxidizing" brazing flux designed specifically for removing carbon or graphite from the surfaces of cast iron. Usually contains an oxidizing component such as manganese dioxide. (Note: This flux often used with the Type C flux to provide the proper tinning action.)

Cast Iron Rod

Type F — Ordinarily made with a borax base and containing alkali salts to aid in fluxing the slag that forms on cast iron. Should permit ready fusion of the welding rod and base metal without leaving gas pockets or inclusions.

Stainless Steel Rod

Type G — A stainless steel welding flux designed to permit complete fusion at the root of a weld without burning. The best test for a flux of this type is to coat the root of a butt joint with the paste and then observe the penetration at the root after making the weld.

Silver Brazing Alloy

Type H — A silver "soldering" flux made from an alkali bi-fluoride and borax or boric acid; gives the best results on both non-ferrous and ferrous alloys, including stainless.

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CRITICAL POINTS

By the Editor

GLAD TO FIND, at a meeting of the American Institute of Electrical Engineers wherein telephone, telegraph and radio engineers discussed their metallurgical problems, that these men really believe that conservation of strategic materials means conservation. Instead of crying on officialdom's shoulder that their services were indispensable, and no obstacles should be set in their way, they have fallen to with a will and given intent study to the problems of substitution. For instance, R. S. BURNAP of Radio Corporation of America described the manifold advantages of nickel as a metal for radio receiving tubes; as a result of a continuing study of the *necessary* characteristics of metal components, considerable substitution of bare steel, melted under controlled conditions and properly processed, has already been made, and further substitution of nickel-plated steel, and carbon-covered steel is to be anticipated.

A world of trouble over 3000 tons of finished metals, the *total* required for tube manufacture in 1941, including military orders.....Likewise R. L. JONES of Bell Telephone Laboratories told of the investigation of 2600 items of equipment. These contained 81 scarce materials, and of these 81 some 30 more plentiful substitutes have been accepted. Again referring specifically to nickel — largely used in the magnetic permalloys and the no less important nickel-silver springs for relays — the 1941 going rate of 1125 tons has been cut by 500 tons.....This amount is probably wasted every month in ordnance steels, needlessly high in alloys.

UNDOUBTEDLY the communications industry is thus paying the penalty of knowing a lot about its real requirements. For years and years large staffs of keen men have studied all aspects of the supply problem — economics, inherent properties, fabrication — in order to

achieve the optimum conditions. Now they are in a position to decide quickly and intelligently on the next best material for a given part or duty. Contrast this with the railroad industry, which for all its virtues, is certainly ultra-conservative in its use of materials.....Consider the freight car bearing: Each journal "brass" is a 25-lb. bronze casting lined with $\frac{1}{16}$ in. of babbitt. How many gasoline driven trucks and tractors do you suppose we would have if

we were that prodigal of expensive metal in engine and transmission bearings?

Sink of Metal in Railroad Car Bearings In them the anti-friction metal is measured in thousandths thickness, and is backed by a stiff steel sleeve. But could the railroads use such a bearing? Confronted with such a proposition, their engineering committee proudly announces a new design saving 8% of the metal! If they were really in earnest about it they would have not been content with less than a 75% saving, and would then find that their rolling stock contains a veritable "sink" of bearing bronze, with 135,000 tons of recoverable copper, 34,000 tons of lead and 11,000 tons of tin.....A harassed Western Electric engineer, replacing a 0.1-oz. brass screw in a terminal post, could not be blamed for being a little restive at the thought of this mountain of useless metal.

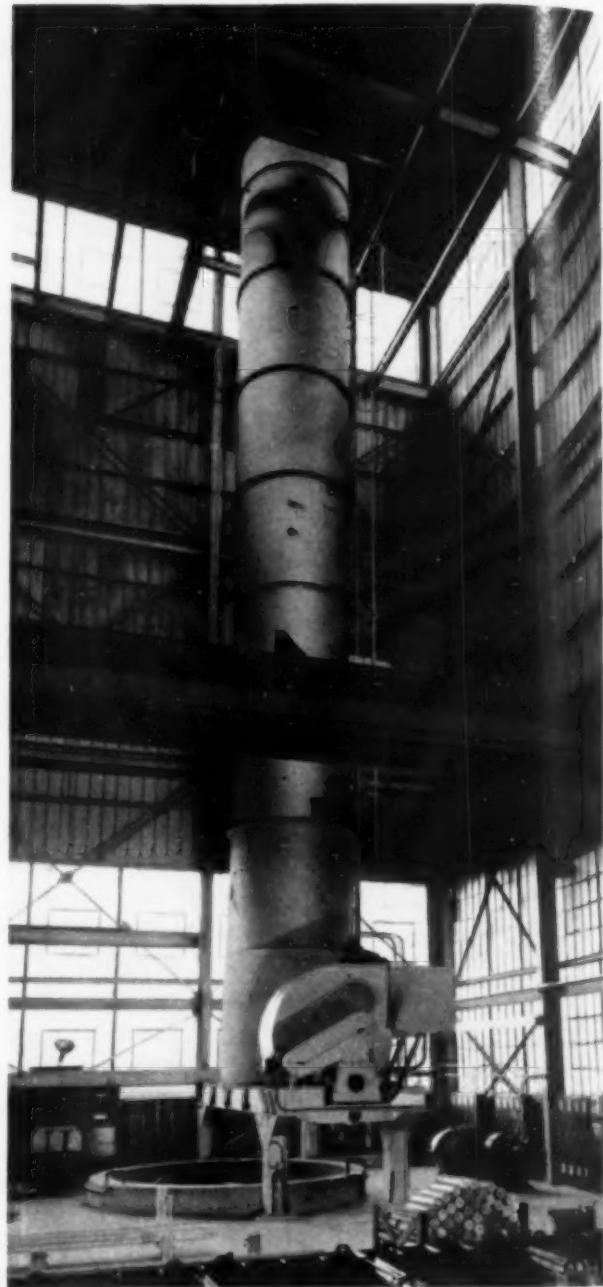
WHICH BRINGS US to some black thoughts on tin. World production in 1941 was on the order of 200,000 long tons, but the Jap has grabbed nearly half of it in Indo-China, Siam and Malaya, and is endangering half of what's left in Dutch East Indies. The situation concerning future supplies is therefore nothing less than desperate. Fortunately Metals Reserve Corp. early started a stock pile; what it now contains the Editor doesn't know, and if he did he couldn't publish it. But an appraisal of the figures for tin production issued by the Inter-

national Tin Council and a consideration of our recent industrial activity shows that it *can't* be much more than a two-year "normal" supply. No matter what it is, we will almost have to "live off our fat" for the duration, and use tin for nothing but absolute essentials. . . . Now, what are we going to do about it? Metallurgists know how to pare down here and there; excellent tin-free and low-tin "bronzes" in considerable number are available for the Army, Navy and Air Corps; lead-base rather than tin-base babbitts have been made into commercial bear-

Tin Cans satisfactory service; solder has
Waste Tin been cut from 50% tin to 25%

tin, and even 15% tin is workable with a soldering tool 200° hotter than usual; less tin may be used in almost every item; many items and uses are prohibited altogether—and so it goes in all consumption except the major one, tin cans! The best the canning industry has been able to do so far is to cut the thickness of the hot-dipped coating by 0.10 lb. per base box, or 7½%. ("All-out" evidently represents a low percentage to both the tinplate men and the railroad men, when it comes to saving critical metal!) This situation could be cured by realistic action in WPB, but in contrast with its prescience in acquiring a stock pile is its present disposition to squander it. Recent news from Washington is that the 1942 allocation for tinplate is almost as much as the last five-year average! By any way of reckoning, this must be at least one quarter of our visible supply. . . . Oh yes, we've cut out half the beer and dog-food cans, but what we want is a HENDERSON who will shake up and wake up the canning industry to the fact that the Japs have shut off our tin as well as our rubber.

REWARDED for a talk to the New Haven Chapter  on "Strategic Metals" by a tour of High Standard Mfg. Co.'s plant for caliber 0.50 Browning machine guns. Drawing on New England's reserve of skilled mechanics and the local pool of expert gun makers (Winchesters have always been made in New Haven), an adequate number of more or less standard tools were assembled and production started without much fuss and any fanfare. . . . The gun, basic weapon of the American Army, is an amazing mechanism, indescribable. Imagine, if possible, parts that are strong enough to withstand firing impacts, yet light enough to fly back and forth 15 times every second, on each round trip



Extruded Aluminum Shapes 76.5 Ft. Long Are Hung in This Electric Resistance Furnace for Heating; Then Quenched by Lowering Into Well, Below Floor Level, Furnace by Westinghouse for Reynolds Metals Co.

Treatment of Machine Gun Parts

spitting out an empty cartridge and belt link, picking up a new round, shoving it into the chamber, closing the breech and firing. The "bolt", a shuttle that is the star performer, is channelled, chambered, drilled and hardened here and there after some 160 machine operations; it costs one-tenth as much as the entire gun. It, as well as many another important part, is a medium carbon steel containing enough chromium and nickel to lend a little depth to the hardening. Raw stock and

ings are spheroidized to Brinell 180 for machinability; surface hardness can later be brought to Rockwell C-57.....Gun barrels must be easily replaceable, for the intense rate of fire destroys the accurate rifling. Many schemes have been tried for cooling; none are without serious objection. The best steel so far discovered is an electric furnace product. It comes in $1\frac{3}{8}$ -in. rounds, is cut to length, normalized, then quenched and drawn, thus being completely heat treated before any machining is done. (Sometimes if heats are especially difficult, the rough machined parts are stress relieved 100° below the previous draw to promote reaming and rifling.) KENNETH IRELAND, metallurgist, said that pilot pieces, run through for each heat of steel, establish the correct heat treatment routine. One barrel

Replaceable Gun Barrels blank in every heat is cut in thirds for test pieces; these are normalized and quenched with a regular load of barrel blanks. One of them is drawn with the regular load; if it comes out to correct hardness and tensile limits the previous heat treatment is continued—otherwise the other two hardened pieces are used to establish a new routine. Minimum tensile limits are 130,000 psi. ultimate, 110,000 yield, 18% elongation in 2 in., and 50% reduction of area.

.....One especially severe machining job is on the side plate—a $\frac{5}{16} \times 5 \times 22$ -in. piece of alloy steel which absorbs the entire recoil, yet has important grooves and lugs left on its inner surface. For most of its length it is milled down from its $\frac{5}{16}$ -in. original thickness to about $\frac{3}{16}$ in. WALTER STOREY, assistant metallurgist, is quite proud of the large milling cutters for this work; 6% tungsten, 6% molybdenum high speed makes 55 pieces per grind as compared to 15 for standard 18-4-1 high speed.....One interesting procedure that cost a day's time in production has since been rectified by the installation of a large hydraulic press. The recoil plate, made of S.A.E. 1095 drill rod, was forced into the gun bolt by the largest arbor press available, but the final seating was done by the recoil during proof firing. Then the bolt had to be removed from the gun and vestiges of the protruding end of the recoil plate ground down smooth. The large press now seats the recoil plate properly so it can be entirely finished before proof firing.....Riveting of side plates to the breech assembly has so far been done by cold spinning. While there are no records of loose rivets in service, this is being

changed to the heading of rivets while they are heated by a strong electric current. Heads of such rivets are actually welded to the plate below, and the shanks *entirely* fill the hole.

DISCOVERED that nickel and monel plates and tankage too large for existing pickling equipment can be de-scaled with paste pickle. Maybe you'd like to know. The creamy dope is brushed on; after it works for an appropriate time it is washed off—scrubbed off with sand or pumice and a stiff brush.

Paste Pickle for Oversize Nickel Tanks

(Also remember that a lot of black oxide and burned surfaces can be avoided by cleaning *before* heat treatment.).....The International Nickel Co. recommends the following formula: Mix 10 lb. fullers earth with 1 lb. lampblack, and add enough of the liquid to form a thick paste that will stick on vertical walls. The liquid is a mixture of 3 gal. of HCl (20° Bé) and $\frac{1}{2}$ pt. HNO₃ (38° Bé) with $1\frac{1}{2}$ lb. cupric chloride dissolved therein. Let it work on monel for 20 to 60 min.; nickel takes 2 to 4 hr. Metal temperature should be about 90° F.....Two precautions: Provide adequate blower ventilation to protect workmen from the fumes. Wash monel with *hot* water. ☺

Get in the **SCRAP**

America's war industries need
METALS
PAPER
OLD RAGS
RUBBER

Get it back in war production

NAILS FROM RUINS OF ST. PIERRE

MONT PELEE, perhaps the most famous of the few active volcanoes on the western hemisphere, is located on the small French island of Martinique in the Lesser Antilles, situated about half way between Puerto Rico and the South American coast. During the eruption of this volcano in 1902, the city of St. Pierre was totally destroyed. Dr. FRANK A. PERRET, volcanologist now stationed at St. Pierre, has assembled a collection of objects which went through the eruption, among them a number of wire nails which had been found in the ruins of the old city; and he was of the opinion that these nails might furnish some clue to the conditions existing in the *nuée ardente* responsible for the catastrophe.

(The term *nuée ardente* is a name given to the peculiar type of rapidly moving clouds of volcanic gas and dust which sometimes constitute the only evidence of a volcanic eruption. More specifically, a *nuée ardente* is generally characterized by a high temperature and a hurricane-like force.)

Some of the nails were given to Dr. ZAY JEFFRIES of the General Electric Co., and later, because of the work done by the Jones & Laughlin Steel Corp. on the nitrogen content of bessemer steel, a few were sent to H. W. GRAHAM, Director of Metallurgy and Research, for examination. The results of the two independent investigations by Jones & Laughlin laboratories and Cleveland Wire Works laboratories of the General Electric Co. have been combined and are presented here because they turned out to be

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Jones & Laughlin Steel Corp.
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parts of an interesting piece of metallurgical detective work.

The accounts of the historic 1902 eruption of Mont Pelee are very interesting, and a brief review of the disaster may be helpful in understanding the condition of these nails.

St. Pierre was located about five miles south of Mont Pelee; at 7:50 a.m. on May 8, 1902, the city was totally destroyed by an eruption of this volcano. Although a number of eruptions had previously occurred and this particular one was not entirely without warning, the blast of hot gases and incandescent dust (*nuée ardente*) which swept down the slope was quite unexpected. It killed some 40,000 people and caused the utter destruction of the city. There was no lava flow or violent earthquake accompanying the eruption — the city was destroyed solely by the discharge of gas and dust which first toppled the buildings and then set fire to them.

At least one major eruption has occurred since 1902, and the volcano is still considered to be active.

Explorers who visited the ruins shortly after the catastrophe reached the conclusion that although the heat of the blast must have been terrific, it was probably only momentary. Some copper telephone wires were not entirely fused and bottles of water were found whose contents were still quite fresh. In the outskirts

of the city nearest the volcano, corpses were superficially charred.

In spite of such accounts by people who had visited the vicinity, the nails which Dr. PROBERT supplied appeared to be "welded" together in large clusters and showed unmistakable evidence that they had been subjected to a high temperature for a considerable period of time. Therefore the probability of a source of local heat other than that from the *nuée ardente* itself cannot be overlooked. Figure 1 shows the appearance of some of the nails.

Description of the Nails—All of the nails submitted were heavily oxidized and most of them were stuck together in clusters. They were originally ten-penny nails, but from outward appearances their thickness was even greater than twenty-penny nails. When one of the nails was broken, it could be seen that

Chemical Analysis of the Scale

CONSTITUENT	CROWELL & MURRAY	JONES & LAUGHLIN
Total Fe	62.35	70.60
Metallic Fe	....	5.6
C	....	0.02
Mn	....	0.27
P	....	0.046
S	0.066	0.035
SiO ₂	7.71	0.45
Al ₂ O ₃	2.13	....
CaO	1.08	....
MgO	0.53	....
N ₂	....	0.005

most of the thickness was made up of a multi-layer scale. The outside layer of this scale was hard, dense, and dull gray; the underlying layer was porous and rather shiny. Beneath this, and in a few other places, a small amount of red rust was present.

Small portions of a number of nails were chosen for metallographic examination, and the brittle scale was removed from the remainder of the specimens for chemical analysis. The resulting scale-free nails ranged from $\frac{1}{2}$ to $\frac{1}{8}$ in. in diameter. (A 10d. nail is nearly $\frac{5}{8}$ in. in diameter.)

Some of these were quite brittle and broke with a coarse crystalline fracture; others were relatively ductile and could be bent before breaking. A small portion from several individual nails was retained for nitrogen determinations; the remaining material was combined for more complete chemical analysis.

Examination of the Scale—The non-metallic scale underwent three different analyses. A. PORITSKY of the Cleveland Wire Works, General Electric Co., made a spectrochemical analysis; chemical analyses were made by Crowell and Murray, Chemists, of Cleveland, and also by the Research and Development Laboratory, Jones & Laughlin Steel Corp., Pittsburgh.

The spectrochemical analysis indicated that, besides iron, the major metallic elements present in the scale were silicon, aluminum, calcium, magnesium, and sodium. Minor elements were manganese, titanium, and chromium. Obviously a large amount of the non-metallic crust consisted of oxidized iron, so that oxygen was also a major constituent. The chemical analyses are shown in the table at the left.

Differences between the analyses can be attributed to a different source or location of the nails during the eruption. The high silica, alumina, lime, and magnesia content of the scale found on the nails examined spectroscopically and chemically by the General Electric Co. must have come from some source outside the iron and is probably due to contamination with volcanic ash. Since the underlying structures of the metallic part of the nails are not greatly different, we must

Fig. 1—Appearance of Nails From St. Pierre; Actual Size. A thick, non-metallic coating completely encases the metallic residue of each nail



assume that slightly different local and external conditions during the formation of the scale were responsible for variations in the scale.

Chemical analysis of samples of dust from the same eruption* indicated that it would have provided a good source for the silica, alumina, lime, and magnesia actually found in the scale. The fairly high percentage of sodium oxide in the dust should be noted since the spectrometer gave sodium as a major element in the scale.

Figure 2, which shows the unetched structure of the scale at 100 diameters, reveals the

ther examination of this area by etching with stannous chloride as well as with 20% hydrofluoric acid led to the conclusion that one of the constituents of the eutectic is iron oxide and the other is a silicate.

The general appearance of the scale and its response to the foregoing tests as well as its chemical composition indicated that it was composed principally of magnetic iron oxide contaminated with varying amounts of volcanic ash. From the physical appearance of the crust and the nails, it was evident that the whole of the

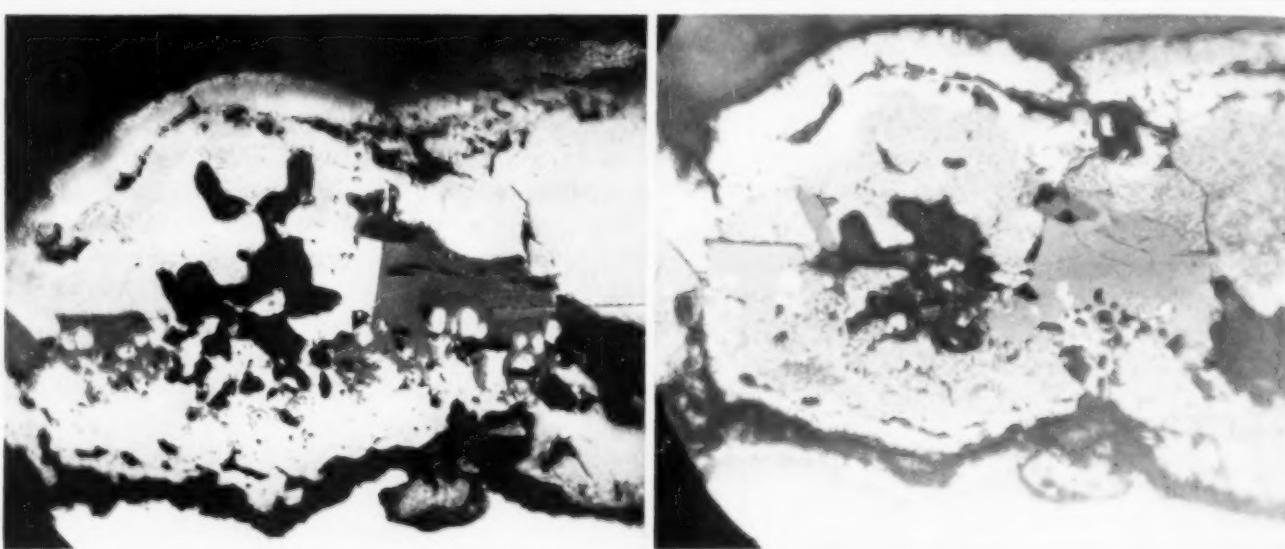


Fig. 2 and 3—Scale on a Typical Nail, Magnified 100 Diameters. Unetched at left and etched with 10% nital at right. White area at bottom is metal; black layer and spots are cavities. Three oxide

phases shown: At top is a thin hard crust that resists nital; etching shows eutectic nature of cloudy constituent (iron oxide and iron silicate); there are also crystals of a dark gray mineral

poor bond between the crust and the metallic core. Three distinct phases can be noted in the scale. The outer layer is a very hard and dense phase, unattacked by nital. The main bulk of the scale seems to be made up of a second phase, cloudy gray before etching. This contains a considerable amount of a third, darker colored phase, in fairly large crystals, mixed in with it. The black portions in the micrographs are cavities. Figure 3, also at 100 diameters, shows that etching with 10% nital develops the eutectic structure of the intermediate constituent. Fur-

crust had not been liquid. The structure is typical of that obtained by sintering at a temperature at which part of the material is liquid and part solid.

Presence of large gas cavities is consistent with this view because these form readily when the material is in a pasty state. Since there is a predominance of iron oxide and silica present in the crust, the possible formation of the compound fayalite, $2 \text{FeO} \cdot \text{SiO}_2$, is not too remote. Fayalite and iron oxide form a eutectic at 76% by weight of fayalite. The melting point of this eutectic is about 2170° F. (1185° C.). There is evidence that the eutectic found in the crust had been melted; if it can be assumed that the eutectic is composed of fayalite and iron oxide, the melting point can be approximated.

Assuming that the presence of impurities

*Analysis by E. COLONNA, *Journal of the Chemical Society of London, Abstracts*, 1904, Vol. 86 II. 59.90% SiO_2 , 17.40% Al_2O_3 , 3.54% Fe_2O_3 , 4.50% FeO , 6.70% CaO , 2.25% MgO , Tr MnO , 0.55% TiO_2 , 3.35% Na_2O , 0.54% K_2O , Tr Li_2O , Tr BaO , Tr SrO , 0.10% Cl , 0.31% S (sulphide), 0.48% SO_3 , 0.11% P_2O_5 , 0.50% loss on ignition, 100.23% total.

Fig. 4—Longitudinal Section of One Nail; Unetched; 500 Diameters. Although the slag inclusions are soft sulphides they are not pulled out into stringers, as in ordinary wire

would not lower the melting point of the pure eutectic by more than about 170° F. (75° C.), it can be estimated that the temperature of the nails, at some stage during the formation of the crust, was around 2000° F. (1100° C.). This, however, does not preclude the possibility that the temperature may actually have been higher.

Sulphide Inclusions—Further investigation of these nails centered on their metallic portion, and endeavored to explain their unusually high nitrogen content, as well as a new microstructural arrangement of the iron nitride. This metallurgical study will be reserved for later presentation.

However we can anticipate a small part of the work by recording here our observations on the sulphide inclusions, since they substantiate the estimated temperature which these relics were subjected to.

The unusual metallographic feature is the amount and type of non-metallic inclusions present. Chemical analysis showed that the metal contained 0.116% sulphur, somewhat higher than commonly associated with ordinary bessemer steels. Much more unusual was the finding that in all the samples examined microscopically the inclusion size was small and very few of those present were elongated in the longitudinal direction. Inasmuch as the majority of the non-metallies were soft sulphides, the

fact that they were more or less globular is significant.

Figure 4 shows a longitudinal section of one of the nails at 500 diameters. The non-metallic inclusions are quite small, and, although this is a longitudinal section, relatively few exhibit any elongation. This is not a normal condition, in view of the amount of reduction that must have taken place in the drawing of the wire from which the nails were made. This agglomerated condition of the inclusions supplied additional information concerning the environment following the eruption.

It has been found that prolonged heating at high temperatures will cause elongated sulphide inclusions first to break up and then to coalesce into globules. Figure 5 illustrates the result of heating cold drawn bessemer free-cutting steel containing 0.118% sulphur for 4 hr. at 2300° F. (1260° C.). The condition of the sulphide inclusions in the cold drawn bar is shown in the left micrograph. The companion was taken from the same bar after heat treatment; the elongated sulphide stringers have disappeared and small globular inclusions have taken their place, strikingly similar to those found in the nails (Fig. 4).

Temperature of Disaster—It has now been fairly well established that the nails were in contact with volcanic dust, and the temperature must have been in the neighborhood of 2000 to 2300° F. (1090 to 1260° C.) for a matter of hours rather than minutes or seconds. The source of the abnormally high nitrogen content of the metallic portions still remains to be explained, and this will be demonstrated in a subsequent article.

Fig. 5—Unetched Specimens Showing the Effect of High Temperature Treatment on the Agglomeration of Elongated Sulphide Inclusions. At left the steel is as cold drawn; at right is the condition of the sulphide inclusions after holding 4 hr. at 2300° F. (1260° C.). The sample treated was a bessemer free-cutting steel containing 0.118% sulphur

WAR PRODUCTS CONSULTATION

Relief of Internal Stress

The Problem

*Posed by a Machine Tool Manufacturer
in New England*

THREE IS a great scarcity of information on the correct heat treatment for stress relieving of even straight carbon steels. I use the term "stress relieving" in its recognized sense as distinct from the term "normalizing", which calls for a heat of approximately 100° F. above the critical range, whereas the temperature for stress relief might be as much as 200 to 300° F. below said range.

My attempts at stress relieving tool and similar parts lead me to believe that other people must have done quite a lot of work on this subject, even though I cannot find the required data in even the highly specialized handbooks such as the 1939 edition of *Metals Handbook*, or the 1941 edition of S.A.E. Handbook.

Materials to be treated would range from S.A.E. 1035 to S.A.E. 4600 series. We have very up-to-date electric furnace equipment to handle this work.

The Suggested Solution

Probably the welding engineers have done the most work on residual or internal stresses and proper means of relieving them. The American Welding Society's "Research Supplement" for November 1937 contains a 64-page summary of 160 technical articles on "shrinkage stresses in welding", and it has some mention of methods of stress relief.

Welding is ordinarily restricted to steels containing 0.35% max. carbon. American Society for Mechanical Engineers' code requires that pressure vessels of certain duty shall be heated uniformly to at least 1100° F. (and to 1200° F. or even higher if the vessel can be supported so as to avoid distortion). BENSON and ALLISON (British Iron & Steel Institute's 1935 Welding Symposium) indicate that a sizable fraction of

the internal stresses are relieved during the heating portion of the cycle; that the higher temperatures are far more effective than the longer times at heat; that 1100° F. will relieve even very high internal stresses down to a value of 2000 to 4000 psi.; that uniform and slow cooling to 200° F. is necessary to avoid re-imposition of thermal stresses.

These above results apply to relatively soft steels. Stress relief undoubtedly involves the creep of metal under load at high temperature; therefore one can assume that steels with high creep resistance will require the maximum temperature to give effective relief. Such steels are very frequently quenched for hardness and strength; in that condition they have very large internal stresses. Stress relief occurs during tempering, but the degree of heat is limited by the permissible softening; hence the desirability of long-time or (preferably) multiple tempering treatments.

"Process annealing" is a common example of relief of internal stress in cold-drawn wire. Ordinary temperatures are 1000 to 1200° F. (as in stress relief of welded structures); the time, measured in hours, is necessary primarily to heat the containers and protective materials. However, only a short time "at heat" is really necessary, even to recrystallize the metal to about its original grain size, as proven by the rapid transit of wires when drawn through hot lead baths or tubes.

Stresses resulting from differential cooling in complicated castings are relieved commercially by heating for 12 hr. at 900° F. Otherwise machining operations, removing some of the stressed metal, upset the internal balance in the rest, and result in intolerable warping.

Machining operations themselves introduce annoying stresses in the sub-surface layers; a stress-relieving anneal may be given parts that require precise dimension or reproducible response to stress. For instance, bourdon tubes of 0.70% C, 0.15% V steel for accurate pressure gages are machined to $\frac{1}{16}$ in. of final size and

gives the following stress relieving treatment (passed in pulverized mica):

Heat to 600° F. at less than 150° F. per hr.;

then to 1380° F. at less than 125° F. per hr.

Hold at 1380° F. for 4 hr.

Cool in furnace at less than 200° F. per hr.

Critique by MAXWELL GENSAMER

Associate Professor of Metallurgy
Carnegie Institute of Technology

Lack of any systematized treatment of the problem in the literature, or even data for specific circumstances, would be serious if these data were not so easily obtained.

A very good approximation of the time necessary to accomplish a certain relaxation of stress at a given temperature can be obtained by simply observing the change in radius of curvature (or the spring-back) of an originally straight beam during annealing while being forced to conform to a certain curvature. There is no reason why the test pieces need be large; small ones such as could be obtained from tool steel would be quite satisfactory.

The method in brief is to take a straight bar, bend it in or around a fixture to such a curvature as will produce a high initial stress

in the outer fibers (under the elastic limit of course), and then hold the curved beam at the desired temperature for a certain period of time; remove the assembly from the furnace; unclamp the beam from the fixture and measure the radius of curvature. The stress required to bend the beam with its newly acquired curvature back to the curvature imposed by the fixture is the value to which the originally high stress has been lowered by relaxation during the annealing heat.

This process can be repeated several times with the same specimen, each time obtaining a point on the stress-time curve. These curves may be straightened out by plotting them logarithmically, and thus make it easier to select a time adequate to lower the stress to a value that seems safe. Some factor of safety should be used, perhaps 2, partly because the rate of relaxation in a body is influenced by the stress distribution.

If creep curves are available for the given steel at the intended stress relieving temperature, one can derive an approximation of the relaxation curve therefrom, but the method is so tedious I doubt it would be much used. Certainly the experimental determination, as outlined above, would take less time and be more accurate.



CRACK SENSITIVITY OF WELDED AIRCRAFT STEEL*

By J. G. Ball

CRACKING in welded aircraft tubing (1% chromium, 0.20% molybdenum steel) is peculiar in that it is much more of a problem in Germany, although the composition and apparent physical characteristics are identical with similar English melts. A very considerable German literature has therefore appeared, discussing the problem, and the present aim is to summarize a dozen articles appearing since 1934.

Many reasons for the cracking of this type of steel during gas welding have been put forward. They include considerations of the method of manufacture, chemical composition and physical characteristics of the steels. While there is much evidence to support each reason which is put for-

ward, there does not appear to be any underlying theory which can embrace all of them.

Steel Melting — One author shows that four heats of basic openhearth steel had a high crack sensitivity, when measured by the rigid assembly test, whereas steels of substantially the same composition (although lower in silicon, manganese and sulphur) were insensitive to cracking. Another author claimed that the nature of the scrap had an influence, and that old Cr-Mo steel should not be included. General agreement is that "special refining" treatments are necessary; melting and refining at high temperature and a long, active boil will reduce crack sensitivity, but controversy exists as to whether this is due to a lower oxygen or hydrogen content or to some other more obscure influence. *(Continued on page 232)*

*Abstracted from *Quarterly Transactions of The British Institute of Welding*, Oct. 1941, p. 181.

MANUFACTURE OF BRONZE PIGMENTS

By Henry H. Mandle
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IN THIS ARTICLE, designed as a chapter in the forthcoming book on powder metallurgy (edited by Prof. JOHN WULFF of Massachusetts Institute of Technology), a few facts are assembled from an old industry utilizing fine particles of metal. At the present time, most uses of the product are interdicted by priorities; nevertheless a discussion may take on interest, if for nothing else than of a metallurgical production that is foreign to most engineering operations. It will be confined to the so-called "bronze powders" of copper or copper alloys, principally used in the graphic and decorative arts. The generic name "bronze powders" has been associated with the industry and trade for over 75 years, succeeding the so-called "gilding powders" or "gilt". Today the name "bronze" or "gold bronze powders" is a misnomer, as these powders are generally made of alpha brasses.

Before the 1914-18 war Germany was the largest producer of bronze powders. The center of the industry near Nuremberg produced approximately 5,000,000 lb. annually, the largest market being in the United States. During that war period plants in the United States expanded and new ones were built, so that today the combined capacity of our eight plants is slightly in excess of 5,000,000 lb. annually. The equipment in all plants is similar, being a mechanical development of the gold-beater's art of hammering and beating the metal into very thin leaflets, then sifting, grading, and polishing. A historical background and description of the machines may be found in articles by OTTO VON SCHLENK in *Metal Industry* (N. Y.)

1917, and OLIVER SMALLEY in *Metal Industry* (London) in 1924.

The modern equipment has been improved to reduce greatly the number of manual attendants, thus eliminating the personal equation and substituting for the skill of the so-called "bronze meister" mechanical or pneumatic feed and discharge of the machines. Grading, hence quality of the product, has been refined with the modern screens and classifiers.

Fundamentally, the manufacture of bronze powders today still remains an arduous, lengthy stamping operation with intermediate screening between batteries of stamps — small replicas of the mills once widely used in the western states to crush gold ore. With successively lighter hammers the metal is cold worked into foil-like pieces, which by work-embrittlement gradually disintegrate into smaller and thinner flakes.

In the stamping operation a very small amount of lubricant such as lard or lard oil is used. The character, amount, and step where it is introduced vary with the alloy and grade manufactured and must be controlled accurately. An excess causes a rapid reduction in particle size, but the flakes are too thick; too little permits agglomeration, heating, or discoloration.

Raw Materials — There are seven principal alloys used. By the addition of zinc to the basic natural copper the desired gradations in color are secured, progressing from the reddest of the so-called "pale-golds" (which are brasses containing approximately 95% Cu, 5% Zn or 85% Cu, 15% Zn) to the so-called "rich-golds", the yellow-green or brasliest of which are

approximately 70% Cu, 30% Zn. These alloys are introduced into the process in one of the following forms, depending on the construction of the stamping machines:

1. Thin ribbons or bands formed by pouring the molten metal on a flywheel, or on the interior of a cylinder as shown in Huth's U. S. patent No. 726,932.

2. Splash metal — small, round disks made as above by restricting the flow of the metal to droplets.

3. Sponge-like nuggets used with Fuchs crushers and stamping machines. These nuggets are produced by pouring the molten metal into a stream of water under pressure, which breaks it up before solidification.

4. Metal punchings and stampings of scrap copper, gilding metal, low brass, or high brass, cut in small pieces and cleaned in a tumbling barrel. This material is seldom used today and then only for the cheapest grades of powder.

Stamping — The raw material is first subjected to the action of the heaviest stamps, weighing approximately 150 lb. This operation produces material known as *schrott* or *schrode* — thin metallic flakes about $\frac{1}{4}$ to $\frac{3}{8}$ -in. mesh. The *schrode* is fed to intermediate stamps weighing about 100 lb., producing so-called "flitters" of about 8 to 14 mesh. These flitters are further reduced in stamp batteries of 90 and 75 lb. successively to the desired fineness. The powder is graded and classified by screens or air flotation and then polished.

Polishing — The polishers are cylindrical

steel shells with serrated surfaces against which the powder is rubbed with rotating brushes. At the same time the attrition of the particles against one another burnishes them, increasing their luster and coverage. In this process various polishing agents are introduced to prepare the surface of the powder for specific uses. For example, it has been known for a long time that less than 0.5% stearic acid was required to give the powder so-called "lac" properties with varnish vehicles. This is now known as "leafing" or "mirroring".

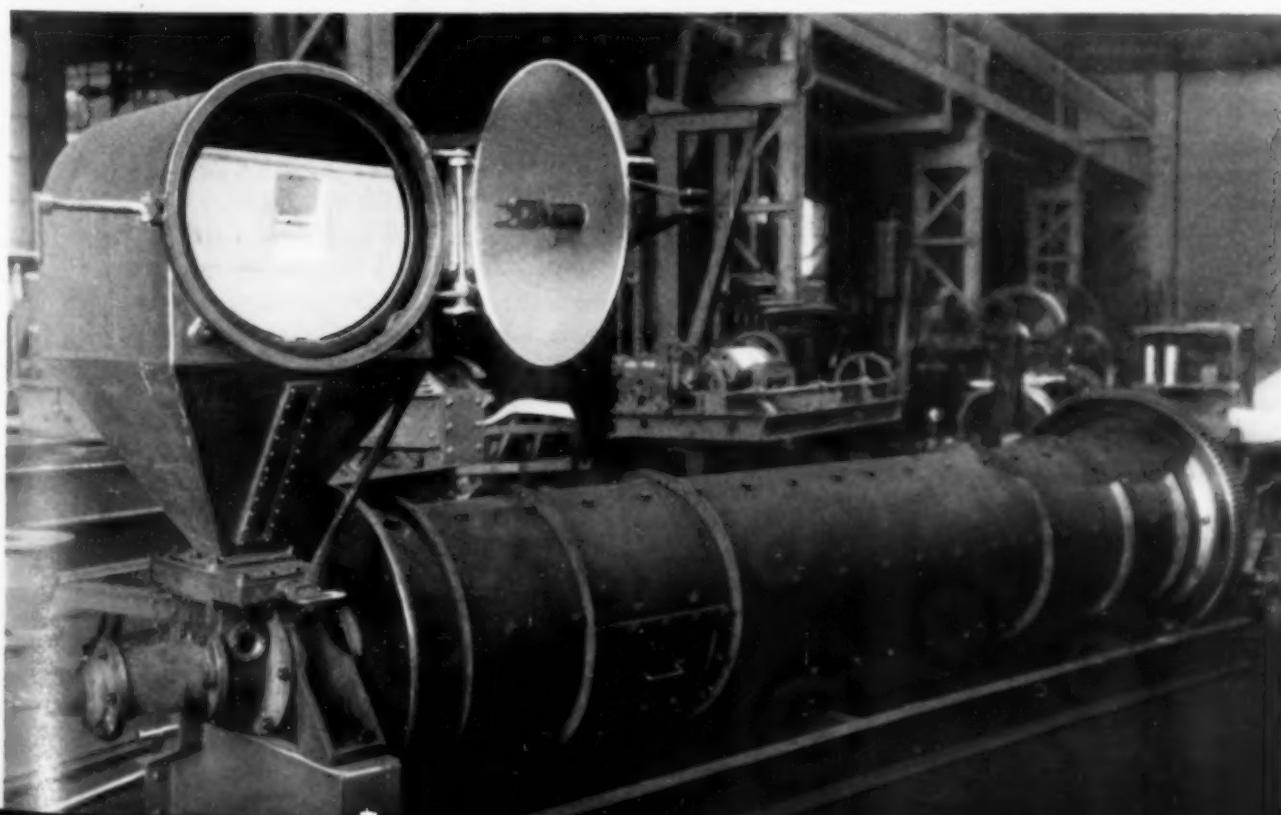
For other purposes such as dusting, bronzing machine operation, water miscible sizes, or lacquers, no stearic acid is necessary; other materials such as olive oil, wetting agents, and various proprietary products are used. The time of polishing varies from 10 to 48 hr., depending on the fineness and application.

The powders may be subjected to a heat coloring treatment which produces colors ranging from the superficial oxide colors of copper — deep red, fire, or crimson — through intermediate colors from the various alloys and different degrees of heat treatment to the green-blue of the brasses. The powders likewise may be treated with acetic acid and heat to produce antique finishes. Some of the alloys are mordanted with tannic acid and dyed with brilliant basic dyestuffs.

All these powders tarnish slowly on exposure to normal atmospheric conditions, and to a greater degree by the action of hydrogen sulphide, ammonia, and other volatile chemicals.

Modern Ball Mill of Mandise Pulverizing System. Hoppers, injectors and ejectors —

the entire circulating system — is in closed circuit and in controlled atmosphere



The tarnish resistance can be improved by the selection of the stamping and polishing agents and careful control of the amount used. Certain highly polar compounds forming compacted dense films show promise as tarnish retardants, but are not definite preventives.

Classification—Bronze powders are classified for various applications. The following will serve as examples:

1. Near-mesh powders (nominally 120 mesh; approximate screen analysis: 40% on 230, 30% on 325, 30% through 325 mesh) for dusting and bronzing machine operation, used in the lithographic industry for labels, calenders, cigar bands, and similar printed items. Note that even this "coarse" powder has 30% through 325 mesh.

2. Medium fine material (nominally 230 mesh; approximate screen analysis: 15% on 325, 85% through 325 mesh) for general decorative work, brush and spray application, coated paper, roller coating, decalcomanias, and embossing transfer foils.

3. Fine material (all through 325 mesh) for intaglio and surface printing, stencils, and the like.

4. Extra fine material (all through 400 mesh) for ink bronzes, linings, striping, etc.

Copper powder has a number of industrial applications, such as in ship bottom anti-fouling paints. It is used in chemical reactions and in the preparation of certain dyes, also as a protective coat for the silvering on mirrors. Formerly a considerable quantity was used in the carbon brush industry for brushes of high electrical conductivity; some is still used mixed with other types of copper powders. A small amount of fine copper is used for hardening magnesium chloride cement and by the medical profession for dressing superficial wounds.

Shape of Flakes

Due to the expanding use of aluminum powder as a paint pigment in recent years there have been innumerable articles in the literature and commercial brochures describing in detail the physical properties and the leaf-like shape of the aluminum powders. The gold bronze powder particles produced in the same manner have the same general configuration. They differ from other metallic aggregates produced by atomization, electrolytic, chemical, or other mechanical means of subdivision. The latter are spheroids, granules or nodules.

The following will illustrate that the metal is forced into flake-like particles for maximum coverage. A pound of raw material having a surface of less than 200 sq.in. and about $\frac{1}{2}$ -in. average thickness is stamped into a coarse 120-mesh powder of an aggregate expanded surface of almost 105,000 sq.in.—in other words, an area 500 times as great as at the start. The average breadth of the particle is about 50 microns (20×10^{-5} in.) and the thickness is 0.80 micron (3.2×10^{-5} in.). This powder would contain 60,000,000 to 100,000,000 particles per gram. The finest lining powders, all—400 mesh, have an average particle size of 25 microns (10×10^{-5} in.) and a thickness of approximately 0.40 micron (1.6×10^{-5} in.). This gives an expanded surface of approximately 220,000 sq.in. or 1100 times the original. This powder would have more than 500,000,000 particles per gram. In both cases the ratio of average particle breadth to thickness exceeds 60 to 1, and for the near-mesh particles it exceeds 100 to 1.

Power Requirements—If the weight, stroke, and number of reciprocations per minute of the hammers are substituted in the usual formula for power, it is found that 0.4 kw-hr. per lb. is required to produce coarse 120-mesh bronze powder, and over 0.85 kw-hr. per lb. for 400 mesh. This is for the stamping operation alone. In actual practice, to stamp and polish a pound of average-grade bronze powder approximately 2 kw-hr. are required.

Ball Milling—During the last five years more emphasis has been placed on greater coverage or thinner flakes. Ball mills, under carefully controlled operating conditions eliminating attrition, are showing marked promise of replacing stamping equipment. Copper powder is available today produced by ball mills under Hall's wet process, U. S. patents No. 1,569,484 and 2,002,891.

Bronze powders are also being produced by ball mills in the improved Hametag-Mand'e dry pulverizing system. The material is circulated in a controlled atmosphere, accurate dosages of the lubricant and polishing agents are automatically added, and the powders are polished if desired. The process is continuous, in contrast with intermittent or batch operation. A modern ball mill of the Mand'e pulverizing system is shown in the photograph on page 215. At a later date a paper will be presented detailing the development of the Hametag system abroad, and a description of the Mand'e dry pulverizing system in this country.

SMALL RADIANT CUPS DIRECT HEAT TO WORK

By Frederic O. Hess
President, The Selas Co.
Philadelphia, Pa.

A NEW method of using gas for industrial heating was developed about five years ago by the author and his associates. It utilized information acquired by scientific studies into the nature of combustion (summarized at intervals in the pages of METAL PROGRESS) — especially the discovery that most combustion spaces are very much larger than necessary. For example, 9,000,000 B.t.u. have been liberated per cubic foot of combustion space from thoroughly pre-mixed gas and air.

Several hundred installations have already been made in surprisingly diverse fields, involving some 35,000 radiant gas burners of special shape. The principle may be called "muffle-less, radiant cup, gas firing". It seems to offer a new approach to difficult heating problems. As a result of five years of experience, many of the theoretical advantages of heating by radiant energy have been proven in practice. Equally significantly, we have discovered in service several beneficial peculiarities of radiant gas firing which we never predicted — and, of course, limitations in certain classes of work.

My purpose now is to summarize and group some of these experiences, in the hope that the reader may be better able to judge whether there may be desirable uses in his own field.

Direct radiant firing by gas was first applied, not by the metal industry, but by the paint and varnish industry. Varnish producers had complained of spotty heating and slow heating — reflected in short pot life, difficult control, and carbonization within the kettle. Our first attempts at direct radiant heating with gas and

air mixtures combusted through and on the surface of porous refractory plates, held promise. But capacities were low and the refractory structures wouldn't stand up. Ultimately we developed a satisfactory construction — differing only slightly from that now used and illustrated in the diagram on the next page.

In brief, the gas-air mixture burns from a multiplicity of radial slots in the refractory tip, along and in contact with the surface of a refractory cup designed to follow the natural sweep of the individual flames. Thus, the cup surface becomes highly incandescent, so that it (a) constitutes an effective source of *radiant* energy of considerable area, (b) accelerates or catalyzes the gas-air reaction so greatly that surprisingly high rates of heat liberation in a small space are achieved, and (c) insures complete combustion before any gases pass beyond the face of the cup into the work chamber.

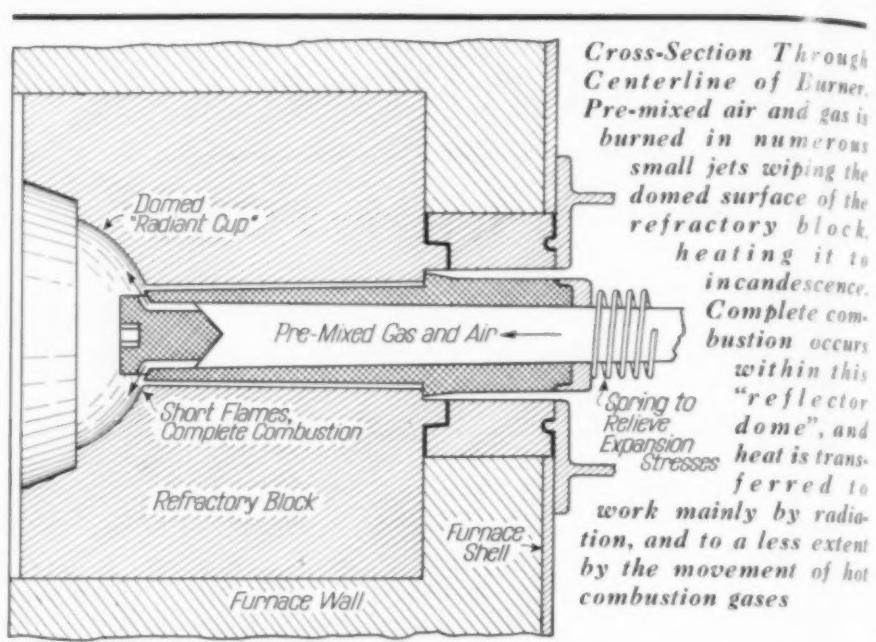
The shape of the cup, further, is desirable for resisting furnace wall stresses, and causes the products of combustion to swirl back into the center of the cup and dissipate their velocity or "blast" before passing out into the work zone. The limitations on cup surface temperatures attainable seem only to be flame temperature and what the refractory can stand. It is interesting to know that we had to go into the refractory business, and develop our own mixes and production methods, to attain long life under heat without cup spalling or crack-

ing, adequately small dimensional tolerances in intricate ceramic forms, and a slotted tip in the base of the cup, which could handle a temperature differential in its 1½-in. length of over 2000° F. between cup temperature and maximum safe allowable temperature of gas-air mixture at the inlet.

The net result of this radically new combustion technique is an efficient source of radiant heat associated with the added benefit of the convected heat carried in products of combustion which do not "blast" or "channel".

Flame impingement is eliminated. (Touchy work is regularly handled within 8 in. of the face of radiant burners.) Combustion is complete because the air-gas reaction is carried to its end point on a hot surface — as hot as 3200° F. in some designs. Heat transfer is extremely rapid because of the radiant character of much of the energy liberated and the fact that the "radiant head", or temperature difference between the source (cup) and the receiver (work) is unusually high. Finally, it is possible to arrange these independently controllable radiant energy sources in almost any pattern and number over any furnace roof, wall or shell — achieving, in effect, large radiant surfaces (some up to 325 ft. in length) capable of adjustment at any point as to the amount of heat generated.

Furnace "Flywheel" Effects Avoided — One practical benefit has been the elimination of the "flywheel" effect in furnace firing. With conventional methods, wherein the entire furnace chamber is brought to heat and the furnace walls themselves become a major heat source, one cannot suddenly change gas inputs and expect sudden drops or rises in furnace temperature. Even if the walls are made of the best insulating refractories, this heat inertia, or flywheel effect, cannot be avoided. But where the radiant burner cups do the heating, and the furnace walls and working chamber are not the predominant heat source, adjustments can be very rapid. Because radiant heat transfer is proportional to the difference of the fourth



powers of the emitting and receiving temperatures on the absolute scale, very slight adjustments in burner temperatures and fuel supplies are immediately reflected in the rates at which work is heated.

In one continuous baking operation at 400° F. the burner faces are at about 2000° F. Only the cups of the burners are incandescent. Adjustments in burner input immediately change the "radiant head", and consequently, temperatures may be cycled almost as rapidly as the thermocouples can react and the controls take hold.

Possibly the most striking accomplishments have been in applications where precise heat distributions are vital. Since the text of this article was first used as a talk before the York Chapter of the American Society for Metals, it was pointed out that furnaces used nearby in Harrisburg with direct firing, multiple burner, radiant roofs have, for four years, been achieving absolute heating uniformity on oxygen cylinders in which the metal mass of the work rolling through the furnace is many times greater near one sidewall, notwithstanding the fact that heat losses are greatest near walls. Therefore, the rows of burners along this wall are simply set for permanent operation at higher rates, and the 1650° F. working temperature is maintained within plus or minus 10° F. at all regions of the work.

Since the members of the American Society for Metals are vitally interested in the correct and rapid heat treatment of ordnance material, it may be mentioned that the experience gained

with oxygen cylinders was directly translated into furnaces for bomb casings. Also, vertical heating towers as high as 20 ft. are performing uniformly within 5° F. (tested every 2 ft. over the entire shell) in both gun manufacture and chemical production—despite the stratifications or stack effects which would make it virtually impossible to insure perfect vertical heat distribution with normal firing methods. Un-equalizing effects are compensated for by burner spacing, sizing, or individual fuel-flow adjustments between the automatic zone or "gang" controls and the individual burners.

Several radiant-roof wire annealing furnaces, such as shown in the photograph, contain 40 or 50 parallel atmosphere tubes in one horizontal plane, and operate up to 2200° F. on nickel-chromium and stainless materials. Roof burner adjustments, across the furnace, assure uniform temperatures on all tubes, be they on the side, in the center or near a wall. Burner adjustments, along the furnace length, provide for greater heat inputs at the entrance end where cold stock streams in.

In strip annealing, controllable radiant gas walls allow manipulations of heating rates along the edges, to avoid the wavy product so familiar in strip mills. Such waviness results simply from variations in expansion or anneal between the edge and the main body of strip.

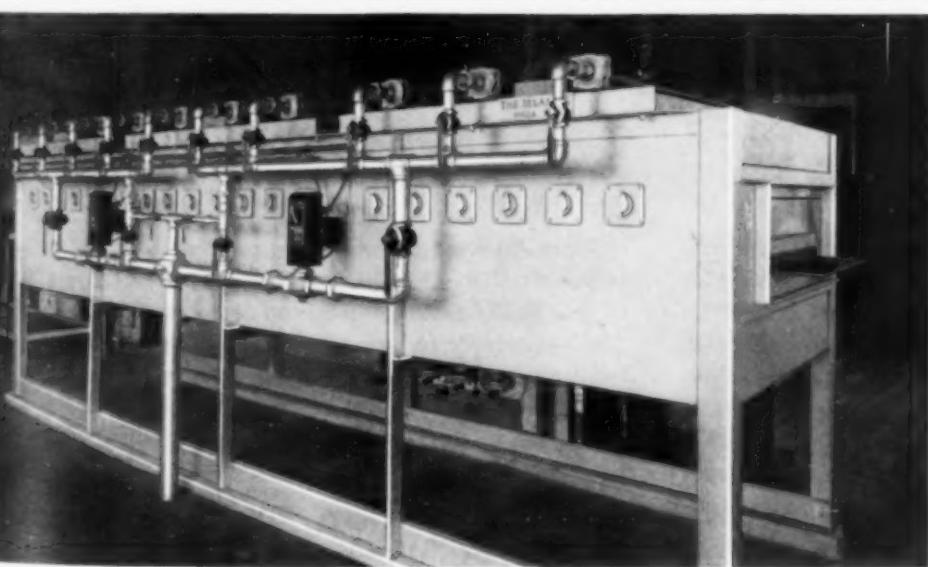
The most notable recent application of

direct radiant firing is in the complex continuous heat treatment of cast tank hulls, weighing 25,000 lb. each and 22 ft. long by 10 ft. across. A group of furnaces now being designed for this service will employ a total of 1500 individual radiant heat sources disposed in the sidewalls in curious patterns to compensate for tremendous variations in metal contour and section. Temperature tolerances are unbelievably small.

Thirteen months of "pilot plant" operation, preparatory to the design of these large furnaces, has been with furnaces 82 ft. long by 11½ ft. wide, for heat treating turrets for medium and light tanks. These furnaces generally have about 50 burners on each side, arranged in a double row, adjusted in size and spacing for the desired heat production. Five independent zone controls are necessary. An overheat monorail has worked very well in these smaller furnaces, and will be installed in the big ones, for nothing but hanger-ends are hot.

Equalizing Time-Temperature Effects—In this connection it is important to realize that multiple-source radiant heat can compensate for many of the temperature-time troubles of heat treatment. With older firing methods, the accepted way of giving the same treatment to both the heavy and the light sections of the same piece is to design for the heavy sections—and just let the light sections "soak" at temperature until the heavy sections are ready. If "time at heat" is a factor (say, in grain growth) heavy and light sections cannot be metallurgically identical after such treatment. Warpage is also bound to be severe. But with multiple-source radiant firing, heat can be "packed" into the heavy sections faster, simply by correct location and adjustment of burners—with the result that heavy and light sections can both experience identical time-temperature cycles.

The completeness of combustion achieved with this type of firing, as well as the blast-free nature of gas flow in



Forty Strands of Nickel-Chromium Wire Annealed While Passing Through 40 Small Tubes in This Furnace, 16 Ft. Long. Two zones of control, 67 radiant cup burners in roof, 9 in. from burner faces (bottom of roof) to atmosphere tubes protecting the work

furnaces thus heated, is demonstrated by the facts that fine ceramic glazes are being direct fired, and that copper, nickel and ferrous alloys (not zinc-bearing or sensitive to the moisture resulting from combustion) are being bright annealed without muffles or special atmospheres.

A factor to look out for is the reflection of heat *from* the work. Highly successful radiant drying of printing inks at high speeds in web presses had to be replaced by "ribbon combustion" when four colors rather than black were printed. The black areas would burn before the yellow ones were dry. Correspondingly, the control temperature of a furnace which continuously bakes the coating inside tubular fluorescent lamps by radiant heat transmitted through the transparent glass seemed anomalously to rise when cold work entered the furnace. However, when the thermocouple was shielded from radiant heat reflected from the tubes, it gave true temperature readings. Incidentally, this roof-heated furnace is an example of temperature control over an area 7 ft. square, complicated by jets throwing cold air into the ends of the traveling tubes along the sides of the chamber, yet the baking temperature is within 10° F. of the glass softening temperature.

Bright metals will not heat by radiant firing as rapidly as dull, nor will white synthetic finishes (as infra-red lamp users have found) cure as rapidly as black. The convected heat from burners of the type described in this article minimizes the effect, but does not eliminate it.

Rate of Heat Transfer—Many industrial demonstrations of high rates of heat transfer and thermal efficiencies could be quoted. A prime reason is that the minor portion of heat inherent in the fuel is delivered in the form of hot furnace gases; exhaust gas temperatures are therefore lower, and less heat goes up the flue. Consequently, 72-ft. furnaces heat treating cast tank turrets show over-all thermal efficiencies of 58%, despite door openings to let the huge work in once every hour. Another example: In continuously annealing by open flame the end cut of 2-in. armor plate (hardened by rapid heat conduction into the cold stock after the cutting torch passes by) one radiant cup burner did the anneal with exactly half the gas consumption of an equivalent bank of small non-radiant flames carefully manipulated for optimum heating. Still another example: Copper is bright annealed at 60 ft. per min. between two radiant banks only 6 ft. long.

SURFACE HARDNESS OF METALS*

By Bruce Chalmers

THE SURFACE layer of a metal may have properties quite different from those of the underlying metal but current methods of testing hardness do not distinguish between them. This article proposes a method whereby surface hardness is measured during static loading, based on the principle that it is possible to apply a very large number of very small indenting forces in such a way that, while each is not under control, the result is statistically definite. Thus, grains of sand or particles of emery dropped from a fixed height onto the specimen make impressions in the surface. The average shape and size of the indentations depend only on the hardness of the material, and the average size of the indentations is measured by the reduction in the specular reflectivity of the surface, which is used as an index of surface hardness.

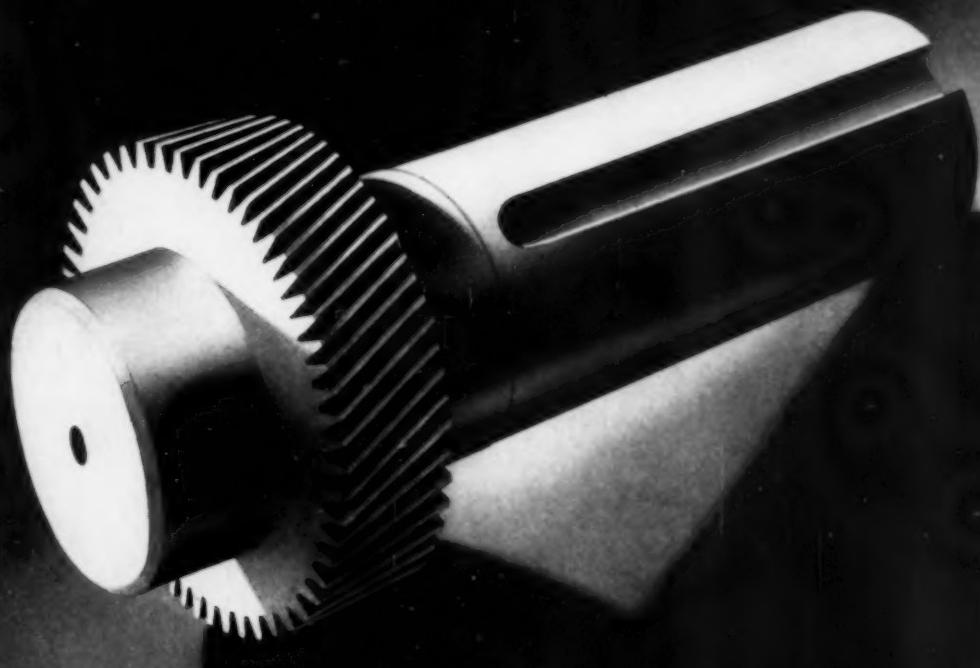
To be more specific: After the surface of the specimen has been cleaned and its reflectivity measured, it is placed obliquely under the end of a tube about 3 ft. long, to the top of which is attached a funnel. The required quantity of sand is placed in the funnel; after running through and striking the specimen, the sand is deflected by a baffle. The specimen is then cleaned by an air blast after which its reflectivity is measured again.

Reflectivity is measured by a 6-volt incandescent bulb which projects a converging beam of light in such a way that the image of the aperture is focused on the specimen at the center of the ellipse that has been indented by the falling sand. The specularly reflected light is collimated by lens onto a photocell whose output is measured by a galvanometer. The size of the aperture is adjusted until the maximum deflection obtained is within the scale-length available.

An alternative to this method of measurement is to balance the output of the photocell by means of a second photocell operating from the same lamp. The amount of light reaching the photocell depends upon the shape of the impression, in turn controlled by the average (*Continued on page 226*)

*Abstracted from the *Journal of the British Institute of Metals*, Vol. 67, 1941, p. 295.

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PERSONALS

A. E. O'Hara has formerly supervisor with Defence Industries Limited, is now with Harrington Tool & Die Co., Montreal.

William L. Courtney is now metallurgist, Regina Industries, Ltd., Regina, Sask., Canada.

John G. Burke, formerly with Bethlehem Steel Co. in the metallurgical department, Johnstown plant, has been called to active duty as 2nd lieutenant in the Ordnance Department and is stationed at Watertown Arsenal.

S. F. Rossiter, formerly assistant metallurgist, is now associate principal inspector of engineering materials, Pratt & Whitney Division, East Hartford, Conn.

Robert E. Liebendorfer has resigned as metallurgical assistant with American Steel & Wire Co., to take a position as metallurgist with Fairchild Aircraft Co.

George F. Landgraf, formerly chief metallurgist, Lebanon Steel Foundry, Lebanon, Pa., is now assistant chief inspector, Bartlett Hayward Division, Koppers Co., Baltimore.

Captain C. R. Laubenfels is now on active duty with the Army Air Corps, in charge of the alighting gear unit of the aircraft laboratory at Wright Field, Dayton, Ohio.

Harry P. Croft, chief metallurgist, Chase Brass & Copper Co., Cleveland, is now copper consultant, Bureau of Industrial Conservation, Office of Production Management.

Byron R. Griffiths, formerly in the metallurgical department, Republic Steel Corp., South Chicago, is now in the metallurgical department of the Studebaker Corp., Aviation Division, Ft. Wayne, Ind.

Louis W. Ballard has returned to Columbia Steel Co., Torrance, Calif., as junior metallurgist, after one year at U. S. Steel Corp. Research Laboratories at Kearny, N. J.

R. G. Roshong has resigned his position with Lindberg Steel Treating Co. to engage in consulting work in Chicago.

Verner Lindstrom, formerly chemist for J. H. Williams & Co., Buffalo, is now in the research laboratory of The Linde Air Products Co. at Tonawanda, N. Y.

Major A. W. Sikes, C.W.S., past chairman of the Chicago Chapter, has been announced as chemical officer, Headquarters Sixth Corps Area, U. S. Army.

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PERSONALS

Arthur L. Collins \oplus has been appointed sales manager by Horace T. Potts Co., Philadelphia.

Frank E. Craig \oplus is now in the physical metallurgy department of the American Smelting & Refining Co., Perth Amboy, N. J.

Promoted by Bliss & Laughlin, Inc.: Clyde Llewelyn \oplus , from general superintendent of the Buffalo plant to assistant to the president.

R. J. Rice \oplus has been granted a leave of absence from his position as metallurgist for Metal Goods Corp., Houston, Texas, to serve as staff expert, Manganese and Chrome Branch, Office of Production Management in Washington.

Frederick C. Hull \oplus , who received his Doctor of Science degree from Carnegie Institute of Technology in June, is now employed at the Westinghouse Research Laboratories as research engineer in the Metallurgical Section.

Russell Fanning \oplus , previously assistant materials engineer at the Navy Yard at Mare Island, Calif., is now physicist and research engineer with Lukas-Harold Corp. of New York and Indiana.

John T. Bryce \oplus has accepted a position as metallurgist with Basic Magnesium, Inc. in Las Vegas, Nev., and is at present in England for a brief stay to study the English process of producing magnesium.

G. Elkins Knable \oplus , formerly special representative, Carnegie-Illinois Steel Corp., Pittsburgh, is now on active duty as a colonel in the Office of the Chief of Ordnance, Washington, D. C.

Lieutenant M. C. Gelman \oplus , formerly instructor in mechanical laboratory in the East New York Vocational High School, has been ordered to active duty with the U. S. Army, and is assigned to the New York Chemical Warfare Procurement District as chief of the Metals and Miscellaneous Inspection Section.

R. H. Williams \oplus is now melting supervisor and metallurgist with McKinnon Industries, Ltd., Division of General Motors Corp., St. Catharines, Ont., Canada.

Arthur F. Braid has resigned after 31 years as sales manager of the Metal & Thermit Corp., and will devote his time to the drawing closer of the United States and Great Britain.

A. P. Bellingshausen \oplus has been assigned to Tokheim Oil Tank and Pump Co., Fort Wayne, Ind., in charge of inspection of ordnance for the War Department.

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A LOW CARBON OPEN HEARTH PRODUCT

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Pace setters in modern industry are repeating the principles set forth by Chippendale and establishing new markets with restyled, attractive products.



HARDNESS

(Continued from page 220)

penetration of the sand particles.

The average depth of indentation does not exceed 0.001 mm., and it is therefore possible to measure the hardness of layers down to 0.01 mm. thick. The hardness is probably largely con-

trolled by a superficial layer, on the order of 0.0002 mm. thick for tin; less for harder materials.

Surface hardness as given by the new method shows a general correspondence with Vickers diamond pyramid hardness.

One field of application is for coatings that are so thin that ordinary indentation methods cannot be applied. Measurements have been made on a series of electroplated tin-copper alloys. Electroplated alloy (69% cop-

per) is as hard as cast speculum metal of the same composition. The composition of maximum hardness corresponds with that of Cu₃Sn. Similar measurements have been made on hot-dipped tin alloy coatings, rhodium flash, and on oxide films.

Some anomalous results for annealed and polished copper and bronze are due to a hard surface on a softer interior. To examine the effect of surface treatments it was decided to adopt, as standard, surfaces prepared by the anodic brightening method without any mechanical action. Such a surface was compared with that obtained after various mechanical polishing operations, and such tests on copper, tin and nickel show the hardening due to various surface treatments.

The increased surface hardness of tin due to polishing or burnishing is retained after annealing at 100° C. for several hours, while the increase in Vickers hardness produced by rolling is removed in less than half an hour under similar conditions. Results on copper, however, have shown that most of the extra hardness due to polishing is removed by annealing. Cathodic treatment in sodium carbonate solution very considerably reduces the surface hardness. Subsequent exposure to air causes a gradual increase in the surface hardness. Storage in an atmosphere of nitrogen prevents recovery of surface hardness.

The method may have useful applications in connection with the surface hardness of glass and plastics and of finishes such as paints and lacquers.

The effect of heat treatment on the polished layer may be of interest when the metal is subject to age hardening, temper hardening, or precipitation. It is possible that the equilibrium of such alloys may differ according to whether or not they constitute a polished layer, since a polished layer is stable under conditions in which the metal in bulk would anneal or recrystallize. This may have some application in connection with bearing surfaces subjected to continued friction.

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ROTOBLAST BARRELS



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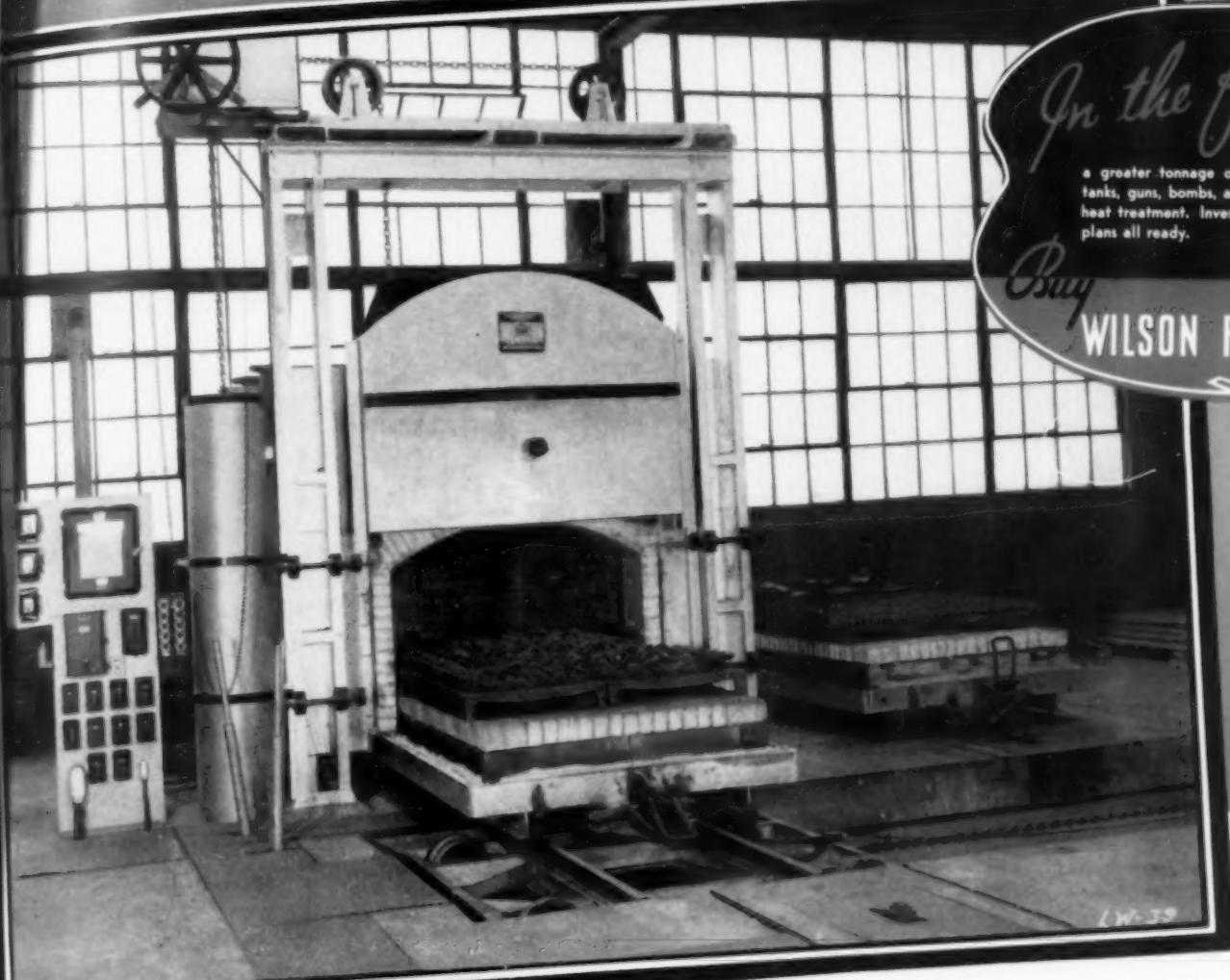
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AIRCRAFT

(Continued from page 213)

The "rigid assembly test" is widely used in German aircraft factories. In it two strips, about 2 in. wide by 0.04 in. thick, are rigidly clamped between circular dies 2 $\frac{3}{4}$ in. apart, and butt-welded together. The dies must

heat no more than 100° C. during the test. Cracks occur mainly in the face of the weld.

Effect of Composition — The composition of a steel is necessarily all-important in determining its final properties, but the exact significance of particular elements when considered in regard to conditions operating during welding is not clear in the light of our present knowledge. For instance, an increase

of carbon actually increases crack sensitivity, although this is probably not due to the effect on the transformation characteristics, as was originally postulated, since the temperature of cracking appears to be well in the austenitic region and around about 1800° F. While this eliminates the possibility that the austenite transformation contributes to cracking, it leaves unanswered the basic problem.

Definite experiments on the influence of individual elements are lacking; most of the authors failed to control other important variables, such as refining temperature and furnace conditions. In general, the German metallurgists do not blame phosphorus as much as sulphur, although the steels tested were quite low in phosphorus — generally less than 0.025%. Sulphur has been given more attention; it would appear that as carbon increases from 0.20 to 0.35%, the sulphur should decrease from 0.030 to 0.015 respectively in electric furnace steels, and from 0.040 to 0.025 in basic openhearth steels deoxidized with manganese. The chemical form of the sulphur in relation to carbon and manganese is important. The increase in manganese displaces equilibrium conditions further toward stability of manganese sulphide which, apparently, is less harmful as regards crack sensitivity.

MÜLLER considers that cracking occurs as a result of weak areas in the metal which are formed by the fusion of certain non-metallic eutectics which have been concentrated by segregation. The eutectic between iron and iron sulphide melts at 1800° F. and the ferrous and manganese sulphides' eutectic at 2160° F. These figures agree with determinations of the cracking temperature.

However, it is probable that such phases would not exist separately, but would contribute to

(Continued on page 240)

HERE'S RADIANT HEAT AT ITS BEST....

MORE TONS HEATED PER DAY

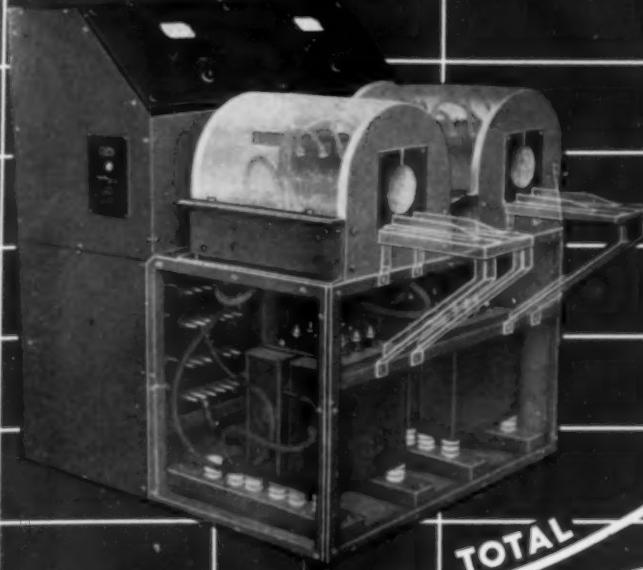
5 Burner Advantages

- Burners may be placed at the sides, ends, top or bottom of furnaces.
- Radiant and convection heat combined in one unit.
- Give fastest heating rate, no flame impingement.
- Heat more tonnage per given hearth area.
- Minimum scale, no decarburization.

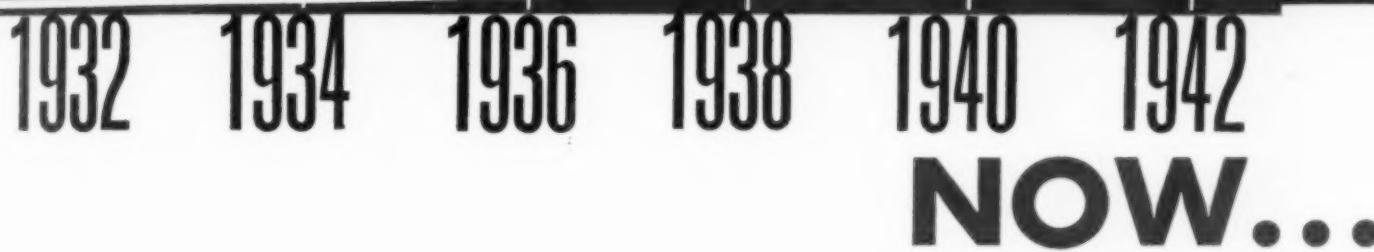
Thermavol FURNACES WITH THERMAVOL BURNERS

ALL types of Thermavol furnaces have established high production records. The Thermavol burners have porous refractory blocks through which a mixture of gas and air pass. The products of combustion burn in beads, as illustrated, slightly off the entire face of the burners. Radiant Heat is thus provided as from an electric grid, with an additional advantage of convection heat obtained by the velocity of the mixture through the burner. Therefore, the highest heating rate possible plus faster penetration are given. Furnace deliveries are prompt. Write for a catalog today.

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The unusual flexibility of Ajax-Northrup High Frequency Equipment may easily be its greatest asset, for you can quickly convert from heating to brazing or melting at any time for a fraction of the original investment.

High frequency heating is being greatly accelerated by the combination of current events. Quantity production floating on conveyors provides an ideal setup. The urgency for speed, maintenance of uniformity and conservation of man power are the deciding factors.

In fact, although little heating equipment had been installed previous to 1936, the sales curve of Ajax-Northrup High Frequency Heating Equipment will soon cross that of the melting equipment which has been used extensively since 1918.

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NORTHRUP AJAX ELECTROTHERMIC CORPORATION, AJAX PARK, TRENTON, N.J.

ASSOCIATE COMPANIES: THE AJAX METAL CO. Non-Ferrous Ingot Metal for foundry use.
AJAX ELECTRIC FURNACE CORPORATION. Ajax-Wyatt Induction Furnaces for melting.
AJAX ELECTRIC CO., Inc. Ajax-Hultgren Salt Bath Furnace and Resistance Type Electric Furnaces.

AIRCRAFT

(Continued from page 232)

the formation of a ternary eutectic, which would melt at a lower temperature than 1800° F. If this were so, cracking only at lower temperatures could be ascribed to loss of cohesion on melting. Also for sudden lack of

cohesion to be a valid cause of cracking, the metal adjacent to the crack should be *rising* in temperature. However, it is more probable that it is cooling down so that an increase of cohesion should occur. On the other hand, this freezing induces lack of plasticity, so that cracking may be due to sudden incapacity to withstand strain.

Temperature of Cracking — It is stated that the cracks are

visible in a darkened room, developing as a red line between the white hot metal and the cold base plate, so that by following along the weld with a thermocouple, the temperature of cracking can be estimated. To determine the facts the sensitive and insensitive steels were welded in irregular sequence, and five observers assisted in the determinations to guard against inaccuracies due to subjective influences. The observed temperatures varied from 1415 to 1940° F., but the majority were in the range 1800 and 1825° F. Again allowing for thermal and visual discrepancies it is probable that cracking commences above 1800° F.

Gas Pressure — The cause of cracking has sometimes been explained on a basis of internal stresses set up by gases, whose solubility changes discontinuously with temperature, or which induce chemical reactions, whose products set up internal stresses. One investigator ascribes cracking to the production of water vapor by reaction of ferrous or manganese oxide with acetylene. Sulphur is said to form hydrogen sulphide, which has the same disruptive influence. This hypothesis, in common with other hypotheses involving hydrogen reactions, does not explain why some poor steels are relatively insensitive to cracking with atomic hydrogen welding.

Others consider that the separation of hydrogen from solution could create a sufficient pressure to rupture the steel, and conclude that it is not the hydrogen content of the base plate, but the increase as a result of welding, which is important. If diffusion of gas from the steel is to occur safely, without creating localized high internal pressures, the nature and causes of weld cracking are likely to vary not only according to the type of metal being welded, but also to its thickness.

Specify R-S Furnaces

OBTAIN THE FURNACE YOU WANT WHEN YOU WANT IT

Time is short. The urgent and unprecedented demand for the implements of war necessitates the full time of experienced hands and minds. R-S Furnaces, designed by experts and proved by experience, are being operated for the heat treatment of steel and other metals used in the manufacture of tanks, planes, ships, guns, mechanized transports, armour plate, shot, shells and armour piercing projectiles. R-S pledges its enthusiastic cooperation and unstinted effort in the all-out production program.

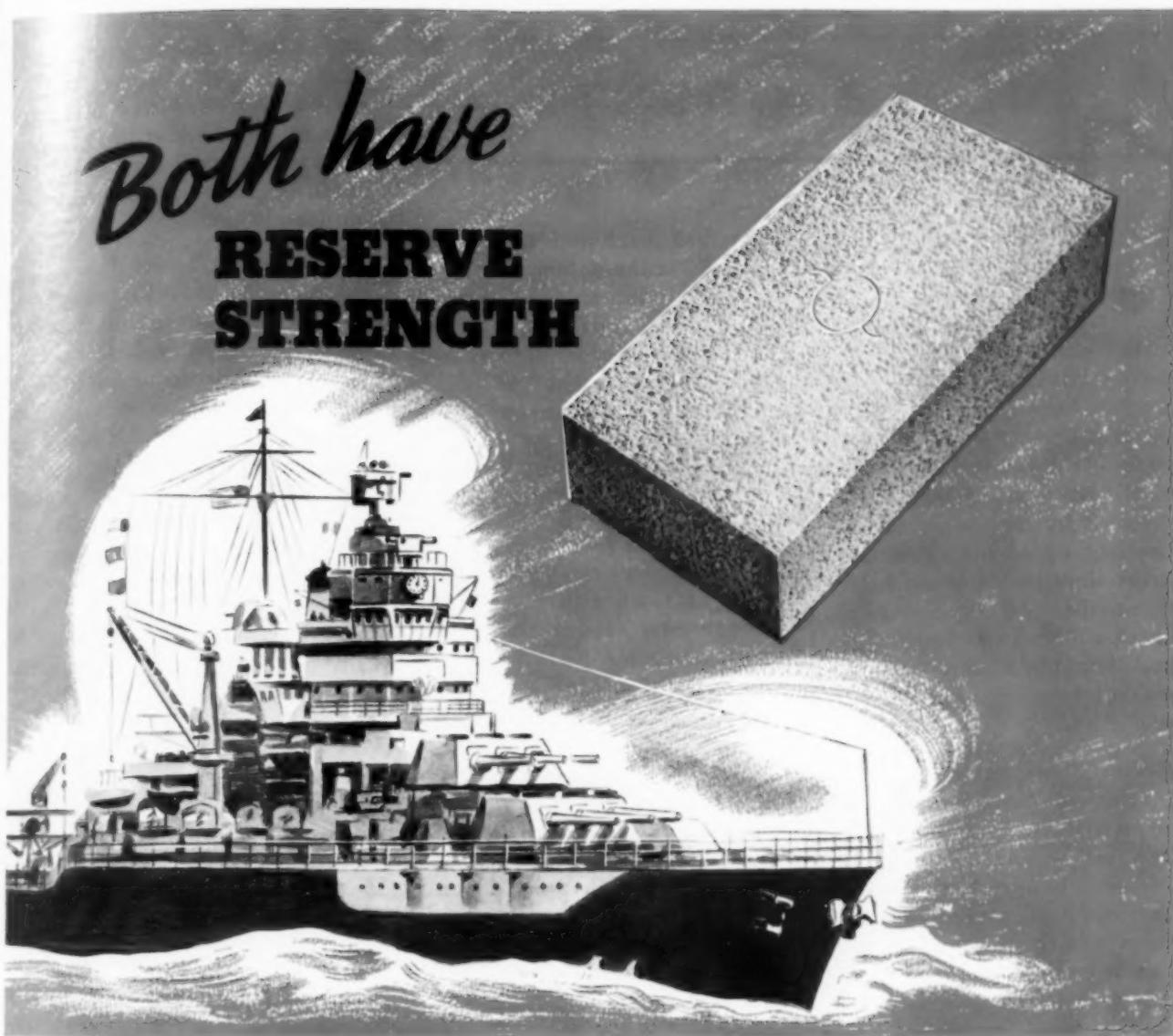
Due to the foresight of R-S Engineers, the furnace you want can be ready for operation sooner than you might reasonably expect.

It will be advantageous for you to discuss heat-treating problems with R-S Engineers.

R-S PRODUCTS CORPORATION
110 Berkley Street
Philadelphia, Pa.

R-S
QUALITY PRODUCTS SINCE 1908

R-S Furnaces of Distinction



. . . and both come through with flying colors when the fire is hot!

The effective strength of B&W Insulating Firebrick proves itself under actual service conditions. They withstand heavy loads and high stresses without deformation.

Strong, yet extremely light in weight, B&W

Insulating Firebrick possess excellent thermal characteristics; give long and satisfactory service under severe service conditions.

Details are given in Bulletin R-2-G, which will be gladly sent upon request.

THE BABCOCK & WILCOX COMPANY • Refractories Division • 85 LIBERTY STREET, NEW YORK, N. Y.

R-159

BABCOCK & WILCOX

NEW PRODUCTS

Check-Analysis of Metals

An instrument, known as the "Identometer", is said to make a very rapid check-analysis of metals and their alloys by comparing their thermal electro-motive force against known materials, thus using the principle of the thermocouple. Very small chemical differences are detected by this non-destructive testing apparatus. Instrument saves time and expense because a number of time-consuming check-analyses can be eliminated and should be of particular interest in laboratory, inspection and tool room. (No. 1)

Rotary Forge Furnace

Burned gases are said to be so handled and distributed in a new oil or gas burning forge furnace to produce extremely uniform heat, assuring fast, uniform production. Atmosphere can be controlled; there is no fly ash to cause excessive wear on forging tools. Furnace is available in 24 and 36 in. sizes and has set new production records in materials. (No. 2)

Castable Refractory

A new light-weight, insulating, castable refractory, "Plicast L-W-1", reduces heat loss and saves fuel, according to manufacturer who recommends it for service up to 2200° F. Heat insulation characteristics are said to be unusually good. Especially suitable for lining heat treating, annealing, stress relieving, carburizing and other industrial furnaces. Available in dry form which sets after being mixed with water. (No. 3)

Blowpipe Tip Speeds Cutting

New design in oxy-acetylene machine cutting tips is said to increase cutting speed of any

standard machine torches by 20 to 30% without increasing oxygen consumption. Tip has nozzle with divergent exit portion, ejecting a narrow, high velocity stream of oxygen, practically free of exit turbulence, that burns a narrower path through the metal and cuts to close tolerances. (No. 4)

Agitator Jets for Pickling Tanks

More steel can be pickled in present tank equipment with these new steam-air agitator jets, according to manufacturer. Properly placed jets speed up the operation by introducing enough steam heat plus enough air for a thorough agitation of all parts of the bath. Outstanding feature of this jet is the orifice "Nocorodal", a perforated graphitic nozzle, unattacked by the acid solutions, and resisting mechanical wear by steam. (No. 5)

Grinds 100 to 400% Faster

"Por-Os-Way" is a new type precision grinding wheel said to take deeper cuts, increasing production per man per machine two to five times. It has a porous structure rather than the usual "sandy" one, yet it grinds hard alloys, copper and aluminum, with minimum loading. (No. 6)

Improved Blast Nozzle

"Heanium", an extremely hard, abrasion resistant ceramic, is now being used instead of metal for the inserts and liners of abrasive blast nozzles. Quoted operating results show that in the sand blasting of metals, the cost of compressed air is kept at a minimum because the nozzle wears so slowly and evenly.

Since the original orifice is preserved after hundreds of hours service, the contour of the blast stream is maintained and the work is cleaned faster and more uniformly. (No. 7)

Custom-Built Welder

A development that may suggest definite advantages for our own war industry has substantially speeded production of Bren gun magazines in a Canadian munitions plant. This is a custom-built atomic hydrogen welder that welds seams in both sides of the magazine in one fixture at one operation, saving much time over the old system of welding the outside of each joint, and then transferring to another fixture for welding the other side of the joint. (No. 8)

Carbide Tool Grinder

Speed with greater accuracy has been developed in a new grinder for carbide tools, according to manufacturer. Available for either 14-in. silicon carbide cup wheels on either end, or one cup wheel on one end and a 14-in. diameter straight wheel on the other end. Has special tool gages, protractors, and tilting table controls. (No. 9)

Temperature Signal Mark

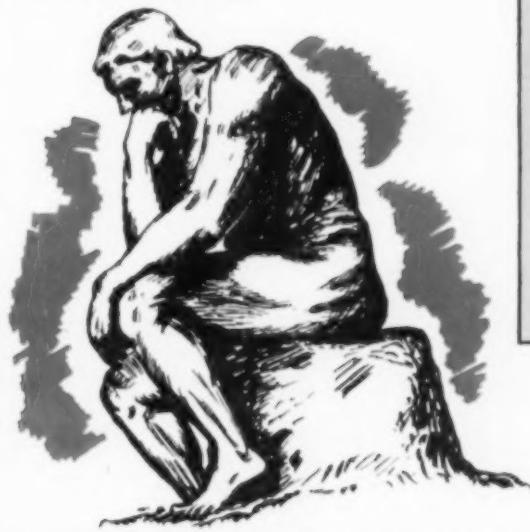
"Tempilstiks" drawn across a heated surface will leave a chalklike mark which melts sharply into a liquid streak when the surface reaches the temperature stamped on the stick, says manufacturer. Available with melting point ranges from 125 to 1600° F. in convenient intervals. Provide a convenient method of signalling desired temperatures on less accessible places, such as vertical, inclined and overhead surfaces, where a fusible pellet would not rest. (No. 10)

(Continued on page 246)

We will gladly pass on to the manufacturers requests for further information on products described here and on Page 246. Mention the paragraph numbers of the items in which you are interested.

GREAT CASTINGS OF YESTERDAY

* Perhaps one of the most duplicated castings in history is that of "The Thinker." From a model made by the famous French sculptor, Auguste Roden, The Thinker was first cast in bronze. Since that time it has been reproduced in many sizes and cast in many different metals.



Great ALUMINUM CASTINGS OF TODAY



BY *National* OF COURSE

Size alone does not necessarily decide quality in castings. Here at National there is a constant flow of quality castings that weigh less than one pound each—some as light as a fraction of an ounce. Then again we are turning out castings weighing over 3,000 pounds. The same skill and craftsmanship go into all National Aluminum Castings.

INDUSTRY HAS OPENED THE THROTTLE!

WE pledge ourselves to work harder—willingly and cooperatively meet increased demands to the best of our ability.

Recently we added a complete new plant with approximately some 200,000 sq. ft. It has been equipped with all modern equipment. And most important of all . . . our men in the shop have pledged their all-out willingness to turn to and produce more.

By those behind the first line of defense, THIS WAR WILL BE WON. We will do our part and cheerfully carry our share of the burden.

• • • —

In addition to T-1 Aluminum Alloy castings that have physical properties that meet the specifications of many commonly used heat-treated castings, we also produce heat-treated TENUAL aluminum castings.

Alloys produced in accordance with Army, Navy, S.A.E. and A.S.T.M. specifications.

T-1 ALUMINUM ALLOY

TENSILE STRENGTH 30,000 lbs. minimum
Elongation 6% WITHOUT HEAT TREATMENT

SPECIFICATIONS

Army Air Corps 11324 Navy Aeronautical M-397
Army Air Corps 11325 Classification AL-31
 Navy 46A1 (INT) Class 6

THE NATIONAL BRONZE AND ALUMINUM FOUNDRY CO.

Twin Plants, CLEVELAND, OHIO

NEW YORK, 111 Broadway • DETROIT, Stephenson Bldg. • CHICAGO, 188 W. Randolph • LOS ANGELES, 405 S. Hill

PRODUCTS

(Continued from page 244)

Convertible Acid Pump

A new series of "Dureo-pumps", in which it is possible to get 480 combinations of alloys, types and sizes with heads and capacities to meet practically any requirements in the han-

dling of acids and corroding liquids. Interchangeable runners and liners, made in all the reliable corrosion resistant alloys, are used where there is apt to be changes in the liquids handled. Conversions can frequently be made without disturbing the setting of the pump. (No. 11)

Strip Welder

An ingenious and inexpensive device for joining strip, end to

end. Consists of two air-operated, opposing guns for spot welding, a notched bar to locate welds, and a control handle to move the gun along, the entire assembly being supported below the transformer. Two or more spots can be welded in quick succession, depending on the width of the strip being joined. (No. 12)

Lubricant for Coiling Machine

Use of "Oildag" lubricant is said to maintain a constant coefficient of friction in a spring coiling machine in which motion stops during cut-off. Production of piston rings from square wire requires high accuracy in cut-off length, and slippage in feed rolls cannot be tolerated. Manufacturer says "Oildag" reduces high and variable static friction in the stopping and starting of the feed mechanism moving the stock through guides. (No. 13)

Flush Quenching Fixture

New fixture for flush quenching of drawing dies with a through axial hole that must be hard, has been designed and put into service by a leading commercial steel treating plant, for hardening dies for cartridge case production. The quenching press consists essentially of a base, a ram, power for which is supplied by an air cylinder, and suitable high speed steel beveled rings to fit the various sizes of dies. The hot die is tightly held in the press so water can be forced through the axial hole without leakage at either top or bottom face. Cost of construction runs between \$150 and \$200. Complete details available. (No. 14)

Shell Heat Treatment

Because requirements for the handling of artillery shells and the tool joints used in well drilling are practically the same, this manufacturer offers its continuous, pusher type roller rail furnace as a proved modern shell furnace. The roller rail permits fast mass production of 75-mm. to 155-mm. projectiles. (No. 15)

USE AEROCARB* FOR RAPID HARDENING, EASY CLEANING IN DEFENSE PRODUCTION



Courtesy of Indian Malleable Company

Economical AEROCARB carburizing materials produce rapid, uniform penetration in case depths from .002" to .030" in low carbon and medium alloy steels. Hardened parts are quickly and easily cleaned after an oil quench by washing in hot cleaning solution.

Uniform results in every heat are assured by using an AEROCARB A activator added at regular intervals to keep the molten bath in chemical balance. This constant balance, moreover, ends the waste and delays caused by "bailing out". Important, too, is the

fact that drag-out losses can be kept to a minimum because of the exceptional fluidity of the AEROCARB bath. No expensive special equipment is required... ordinary commercial pot furnaces can be used with the AEROCARB materials.

Write for full information on AEROCARB... AEROCASE... and other carburizing and case hardening compounds made by Cyanamid. Cyanamid field engineers will be glad to consult with you to help solve your case hardening and heat treating problems.

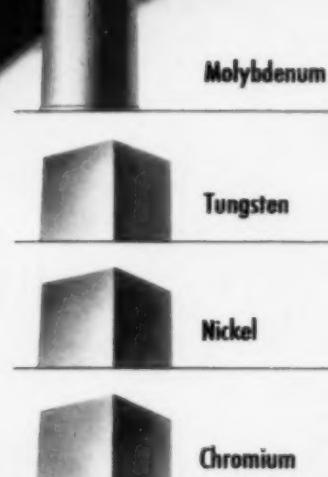
*Reg. U. S. Pat. Off.

AMERICAN CYANAMID
& CHEMICAL CORPORATION



A Unit of American Cyanamid Company
30 ROCKEFELLER PLAZA, NEW YORK, N. Y.

DISTRICT OFFICES: 89 Broad St., Boston, Mass.; 401 N. Broad St., Philadelphia, Pa.; Russell & Bayard Sts., Baltimore, Md.; 3333 Wilkinson Blvd., Charlotte, N. C.; 850 Leeder Bldg., Cleveland, O.; 20 N. Wacker Drive, Chicago, Ill.; Miller Road, Kalamazoo, Mich.; 931 Fisher Bldg., Detroit, Mich.; 900 Shell Bldg., St. Louis, Mo.; Azusa, Calif.



MOLYBDENUM is not a substitute



AMERICAN Production, American Distribution,
American Control - completely integrated.
Mines: Tucson, Arizona; Questa, New Mexico.
Smelting and Refining Works: York, Pa., Washington, Pa.
Offices and Warehouses: Pittsburgh, New York, Chicago,
Detroit, Los Angeles, San Francisco, Seattle.
Sales Representatives: Edgar L. Fink, Detroit; H. C.
Donaldson & Co., Los Angeles, San Francisco,
Seattle.
Ample stocks, sales facilities, technical advice available.

Nor for manganese, or nickel, or any element of sovereign virtue.

Yet Molybdenum and some of these other alloying elements can be employed, each according to its own nature, for many exacting requirements, and physical properties can be developed that give entirely satisfactory performance.

Such a recourse is very important when some of the materials in question become scarce while others are still abundant.

Molybdenum can be obtained for all desired uses. The knowledge of what can be done with it has been greatly extended, and its possibilities go far beyond what had been supposed. New literature is available.

Molybdenum is not a substitute for any other metal, in the sense that it can be used precisely as they are, with identical results. For tungsten, in that sense, there is no substitute. Nor for chromium.



MOLYBDENUM CORPORATION OF AMERICA
GRANT BUILDING, PITTSBURGH, PA.

CONTRIBUTORS

THE PROCEDURE described in the article on drawability (page 192) was developed in the research laboratory of the Victor Mfg. & Gasket Co., where the author, Thomas F. Mika, is research metallurgist and chemist. He is a graduate of Lewis Institute of Chicago in 1937 and has also studied in the graduate school of University of Chicago. In 1939-40 he served on the publicity committee, Chicago Chapter Σ , and is a member of the Chemical Arts Forum of Chicago. He is also the author of an article on "The Rapid Method of Brass Plating Analysis" and co-holder of two American patents on asbestos compositions.

Frederic O. Hess was born in Germany, and after a conventional 13 years of preparatory school, went to the Handels Hochschule in Nuremberg and Technische Hochschule in Munich to study engineering and industrial management. In 1923 he migrated to the United States to acquaint himself with American business practice and has remained here ever since. Mr. HESS worked for several years in Hartford, Conn. in the field of automatic machine design, and in 1926 joined the Selas Co. as a design engineer. He became vice-president in 1930 and president in

1935. "This association," says Mr. HESS, "with the opportunity to operate in the fascinating field of industrial gas application, was one of the prime factors in bringing about my decision to become an American citizen and remain here."

Another young author in this issue is George P. Lenz, Jr., metallurgist for Union Drawn Steel Division of Republic Steel Corp. He has been with Union Drawn since 1937, when he was graduated from Carnegie Institute of Technology with a B.S. in metallurgy. His study of elastic determinations was instigated by the large increase in the amount of physical testing since the national emergency. It should help in supplying materials ordered to government specifications.

Henry Clay Fisher's article on rammed linings on page 188 is a supplement to one in the August 1941 issue of METAL PROGRESS covering molded refractories. Mr. FISHER is refractories sales engineer with Norton Co. in Worcester, Mass. His B.S. in mining engineering came from Oregon State College in 1922 and his M.S. in metallurgy from University of Washington in 1924.

(Continued on page 264)



Thomas F. Mika



George H. Enzian



Frederic O. Hess



George P. Lenz, Jr.



Hugh F. Beegly



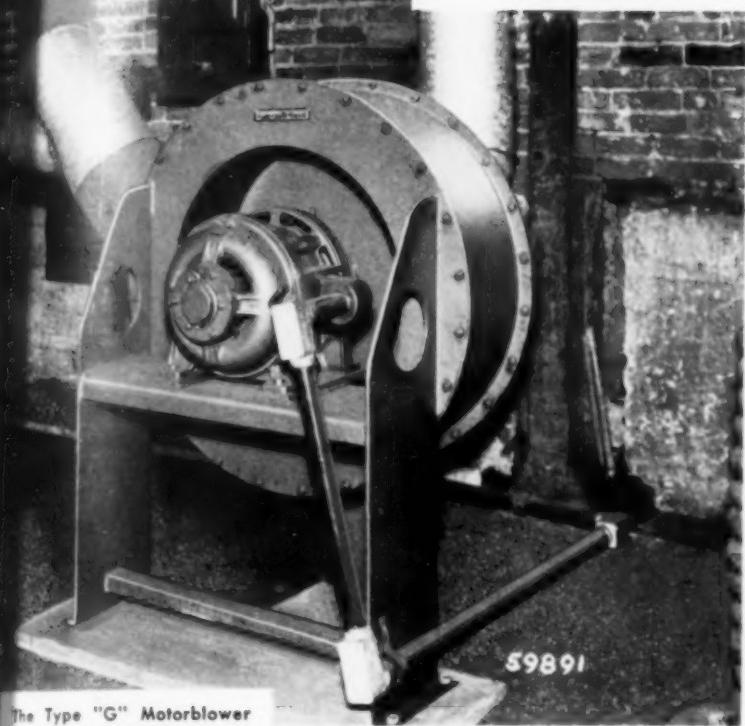
Peter P. Tarasov



Henry C. Fisher

Type "G" *MOTORBLOWER*

**supplies the air for
the forge shop of
a busy chain and
anchor manufacturer**



The Type "G" Motorblower shown above supplies up to 3000 cfm. at 1 lb. pressure to the air loop which serves numerous forge furnaces. Air to one pair of furnaces goes through an underground pipe.



Above: Links of special alloy chain are forged in this corner of the shop.

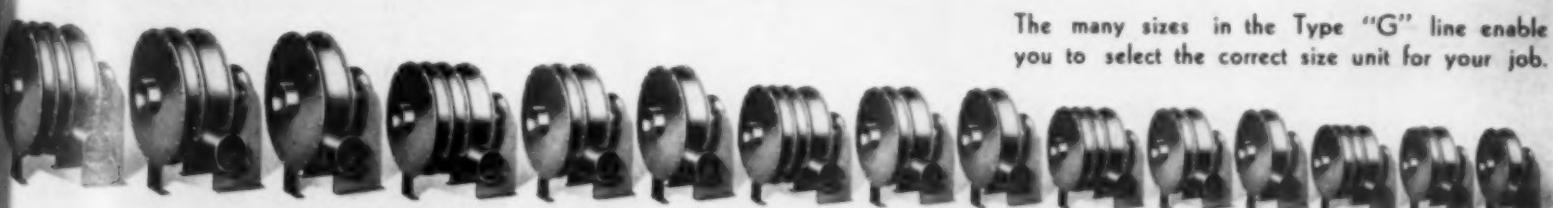
Marine equipment is in great demand today. Any delay or breakdown of production machinery is extremely costly.

To forestall shortages or failures of the air supply to its forge furnaces, one east-coast chain and anchor maker recently replaced out-moded blower equipment with the Type "G" Motorblower pictured above. This Ingersoll-Rand unit was selected because it combined high overall operating efficiency with design features necessary for long and dependable service.

Sizes range from 2 to 30 hp. Pressures $\frac{1}{2}$ to $2\frac{1}{4}$ lb., and capacities from 100 to 4500 cfm.

The complete line of Ingersoll-Rand Turbo Blowers includes machines ranging in size up to 14,500 hp, with capacities to 100,000 cfm, and built for a wide range of pressures.

The many sizes in the Type "G" line enable you to select the correct size unit for your job.



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Scranton
Seattle
St. Louis
St. Paul
Tulsa
Washington

A U T H O R S

(Continued from page 254)

Of the three authors of the interesting bit of metallurgical detective work reported on page 208, **George H. Enzian** has been employed by Jones and Laughlin Steel Corp. since graduation from Lehigh University with a B.S. in

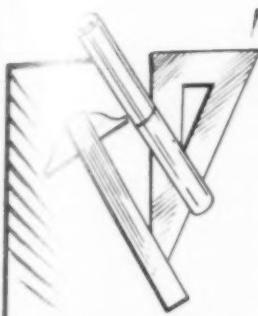
metallurgical engineering in 1935. He was associated with the J. & L. Pittsburgh Works Metallurgical Department, first as an inspector and later as an investigator. In April 1937 he assumed his present position as a member of the metallurgical staff of the Research and Development Laboratory. For the past year he has also been serving the Pennsylvania State College as an instructor of defense courses.

Hugh F. Beegly is also with Jones and Laughlin, and is a 1936 graduate of West Virginia University with a B.S. in chemical engineering. He worked first in the metallurgical division of the Aliquippa Works as inspector and chemist, and has been research chemist at the Research and Development Laboratory since early in 1938.

The third author of the article about nails from St. Pierre is **Peter P. Tarasov**, who made part of the investigations in the Cleveland Wire Works of General Electric Co., where he is metallographer. Born in Russia and educated at Moscow University, he came to the United States during World War I and worked for the Russian Artillery Commission as an inspector in the manufacture of brass cartridge cases. He joined the G.E. Wire Works in 1918 and liked it so well he stayed. His main field of interest is the production of tungsten and molybdenum.

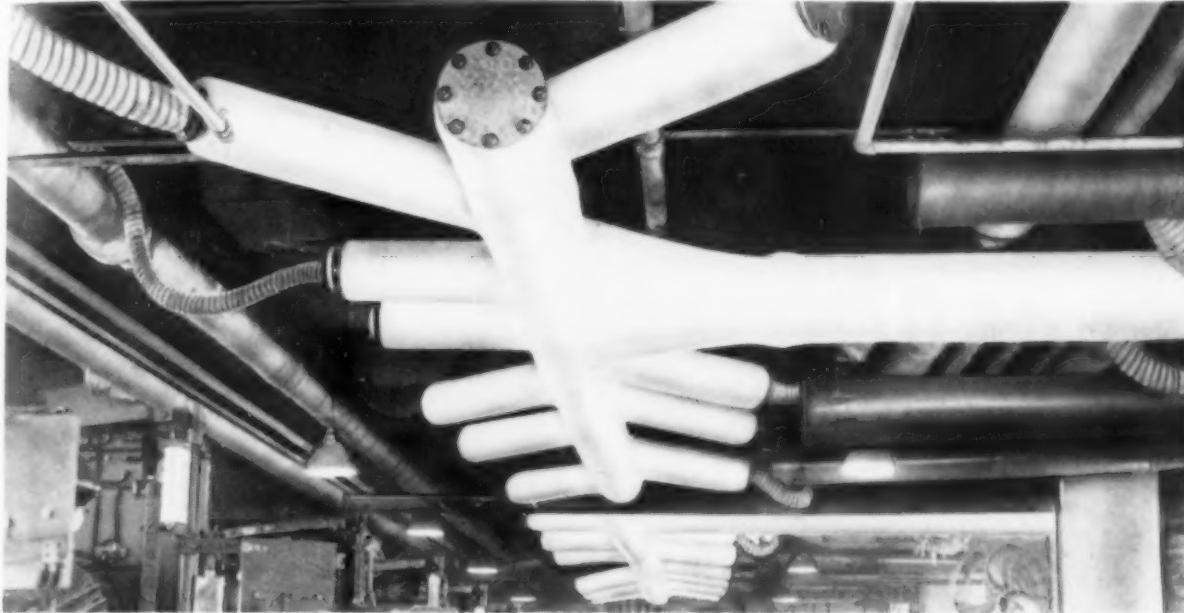
from 1,000 to 30,000 c. f. h.
the Kemp Atmos Gas Producer is designed to fit
the job including the auxiliaries most efficient in pro-
ducing the desired results for the specific material being
treated. Kemp experience will be helpful in meeting
your bright annealing problem. It is yours on
request. Address **The C. M. Kemp Mig. Co.**
405 E. Oliver St., Baltimore, Md.

KEMP of BALTIMORE



TO YOUR SPECIFICATIONS!

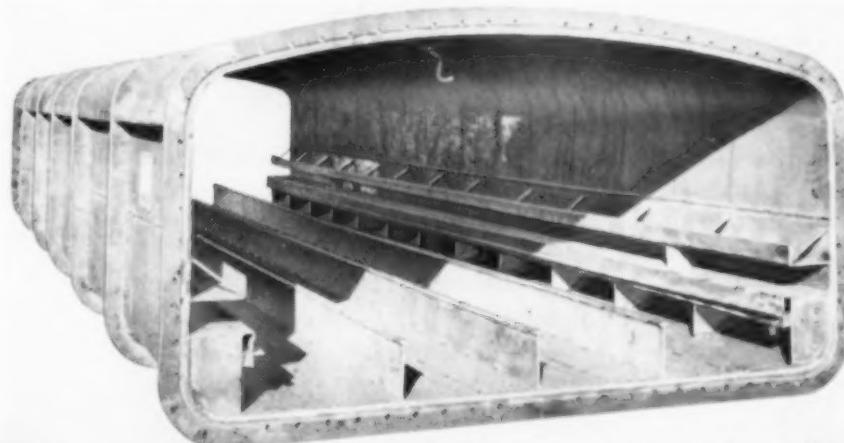
A modern stream-line plant, equipped to manufacture your product, to your specifications. We have specialized in the production of difficult and complicated mechanical assignments for many years—the training of our personnel in the manufacture of Carburizing and Annealing equipment makes this possible. Specify that neat, difficult job to "Pressed Steel" and get "Perfect Service".



Above is a photograph of the actual installation of an Alloy Exhaust Manifold made for a large motor car manufacturer. It takes exhaust gases from motor testing blocks.

Below is a completed Alloy Retort recently made for a large brass manufacturer. It is 19 ft. 6 in. long, 6 ft. wide, 3 ft. high; weighs 5400 lbs.

At right is an inside view of the Alloy Retort which gives an idea of the way in which special construction is possible to meet customer's specifications.



Pressed Steel Company Products: Carburizing and Annealing Boxes, Thermocouple Protection Tubes, Seamless Steel Cylinder Caps, Seamless Steel Neck Rings, Welded Alloy Tubing for High Temperature and Corrosive Application, Radiant Tubes, Inner Covers, and Base Sheaths for Steel Mills.

THE PRESSED STEEL COMPANY
OF WILKES-BARRE, PENNSYLVANIA

STRUCTURE

(Continued from page 186)

by the size factor, there is a very general tendency for the solubility to increase with rising temperature, so that an age hardening alloy may result.

(In this line of approach the principal difficulty lies in assign-

ing a definite size to an atom. It cannot be regarded as possessing any sharp bounding surface, but is to be thought of as a positively charged nucleus surrounded by a cloud of negatively charged electricity, formed by the negatively charged electrons in the different quantum shells. In the normal metal, the outermost or valency electrons are held in common by the crystal as a whole, and the "atomic diameter" is assumed to be the closest

distance of approach of atoms in crystalline elements.)

This size factor was discovered from a study of the copper and the silver systems. Later work has shown that solid solutions of magnesium, iron and aluminum also follow this rule. Therefore, in the formulation of new solid solution alloys of two or more metals, consideration of atomic size factors alone will at once enable us to rule out certain metals, and attention can be concentrated on the more probable combinations.

In considering the additional factors which control the formation of primary solid solutions, the next general principle which we have established may be summarized by saying that, when the size factors are favorable, wide solid solutions are formed most readily when the two metals have the same valency.

For example, in the case of magnesium, a di-valent element, solid solution is greatest with cadmium, also di-valent, and a continuous series of solid solutions is formed at high temperatures. In cases where the valencies are unequal, the general tendency is for the solid solution to be more restricted as the valencies become more unequal. Thus, in the Mg-Ag system the solidus and liquidus fall steeply and the solid solution is restricted, since silver has a lower valency than magnesium.

There are occasional exceptions to these principles, such as Cu-Al, where the liquidus and solidus depressions are very small, but in so far as alloys with a wide freezing range are undesirable, we have these direct hints as to what combination of metals should in general be avoided.

The equilibrium diagrams of the systems Mg-Sn and Mg-Sb are clearly of quite a different nature. This is because the electropositive nature of magnesium and the relatively electronegative nature of tin or antimony form stable compounds. The term "electrochemical factor" denotes the influence exerted by such differences in

(Continued on page 284)

JESSOP C.N.S.
HIGH CARBON-HIGH CHROME DIE STEEL
Conerves

- MATERIALS
- MACHINES
- MAN HOURS

FOR WAR TIME PRODUCTION

The high wear resistance of Jessop C. N. S. die steel results in more pieces per grind of die, and its deep hardening characteristics permit more grinds per die. The increased production from C. N. S. saves die steel, reduces die setup and maintenance time, conserves the time of die makers, and lessens the burden on die making machines and grinding equipment.

War time economy demands the greatest possible production from men, materials, and machines. Jessop C. N. S. High Carbon-High Chromium Die Steel fulfills this need. Write for descriptive folder (Bulletin 441).

JESSOP STEEL COMPANY
General Offices and Works
WASHINGTON, PENNA., U. S. A.



JESSOP STEELS FOR AMERICA
AND HER ALLIES
CARBON · HIGH SPEED · SPECIAL ALLOY · STAINLESS · COMPOSITE STEELS

ASK US ANOTHER

Here's a problem we solved for a user of rabble blades. Perhaps we can help you also.

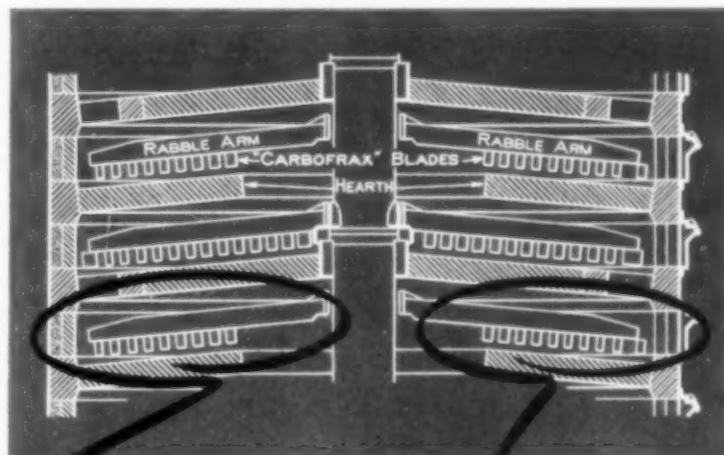
THE rabble blades that transport ores and other materials through single and multiple hearth roasting furnaces are usually subject to very severe conditions. Generally made of alloy steel, they are often eaten away quickly because of the combination of high temperatures, abrasion and corrosion. Frequent replacement, high maintenance expense and costly loss of production are the result.

One user of multiple hearth furnaces decided to do something about it and put the problem up to us. After thorough study, our engineers recommended a trial of specially designed blades made of "Carbofrax," the silicon carbide super refractory. A comparison of the alloy steel blades and "Carbofrax" blades is shown below. The high resistance of "Carbofrax" to

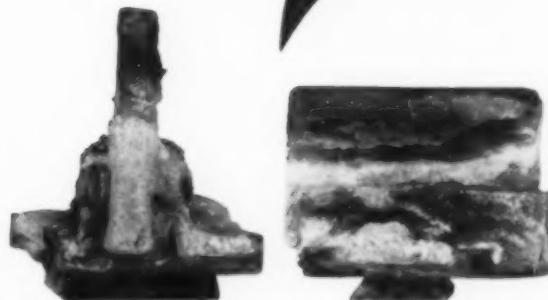
corrosion, abrasion and high temperatures has resulted in increased furnace production and in greatly reduced material replacement and labor costs.

This story typifies the longer life, improved results and lower costs that the Carborundum

Company's special refractory products and research are making possible throughout the metallurgical, chemical and process industries, and in the field of heat treating. Whatever your use of refractories perhaps we can help you, too!



SIDE AND END VIEWS OF alloy steel blade after six months' service. Steel blade has been corroded to such an extent that little of the original shape remains. In fact, after four months, the condition of the alloy blade was so bad that it was entirely ineffective.



SIDE AND END VIEWS OF "Carbofrax" blade after six months' service in same furnace. Because of outstanding resistance to corrosion, abrasion and high temperatures, the "Carbofrax" blade is practically unaffected and still capable of considerable service.



THE CARBORUNDUM COMPANY, REFRactory DIVISION, PERTH AMBOY, N. J.

District Sales Branches: Chicago, Philadelphia, Detroit, Cleveland, Boston, Pittsburgh. Distributors: McConnell Sales and Engineering Corp., Birmingham, Ala.; Christy Firebrick Company, St. Louis, Mo.; Harrison & Company, Salt Lake City, Utah; Pacific Abrasive Supply Co., Los Angeles, San Francisco, Calif.; Denver Fire Clay Company, El Paso, Texas; Smith-Sharpe Co., Minneapolis, Minn.

(Carborundum and Carbofrax are registered trade-marks of and indicate manufacture by The Carborundum Company.)

STRUCTURE

(Starts on page 186)

electrochemical characteristics, and it is a general principle that a high electrochemical factor tends to restrict the formation of a wide range of primary solid solution, and the two metals tend to form a stable compound.

In such cases if a restricted solid solution is formed it tends to show an increased solid solubility with rising temperature. Increased temperature produces larger thermal oscillation, and so makes it easier for a lattice to accommodate foreign atoms, and, apart from this, increase of temperature favors partial decomposition of the compound, so that the solute atoms tend to pass from the compound to the solid solution.

In ternary alloys the same considerations apply not merely to compounds between the solvent and one of the solute elements, but also to compounds between the solute elements.

Other lines of investigation have been fruitful. For instance, it is now possible to compute the hardness of a solid solution from its lattice distortion and the physical constants of its constituent metals.

Study of intermediate phases in alloy systems leads to the discovery that there is no sharp distinction between different classes of compounds, but that various types of intermediate phases merge into one another. The first and most simple phenomenon is that of superlattice formation, where it is found that certain solid solutions at high temperatures have the different kinds of atoms arranged at random on a common lattice, while at low temperatures, although the general lattice type is preserved, the two kinds of atoms rearrange themselves so that each takes up a regular set of positions relative to the other.

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